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(Supersedes IMR No. 601)

AN INVESTIGATION OF THE IMPACT RESISTANCE OF GLAZING MATERIALS FOR RAILROAD VEHICLES

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John A. Rakaczky

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A test program was conducted to determine the impact resistance of several types of glazing materials and thereby develop criteria for the protective glazing to be used in railroad vehicles such as locomotives, cabooses, and passenger coaches. Twenty (20) materials were subjected to the impacts of small arms projectiles, hand-thrown missiles, and heavy, suspended objects. Results indicated that there are materials currently available as "off the shelf" items that would provide protection from the following threats: (1) a 22-caliber, high-velocity, long rifle projectile fired from a distance

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of 92 meters (300 feet), (2) hand-held objects such as rocks or railroad spikes thrown from a distance of 8 meters (about 25 feet); and (3) a heavy, suspended object such as a cinder block struck at a vehicle speed of 48 km/hr (30 mph).

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I. INTRODUCTION

A problem currently exists on the nation's railroads where acts of vandalism have resulted in considerable damage to property and numerous injuries to personnel. Specifically, these acts have usually consisted of throwing objects such as bricks, stones, railroad spikes, etc. at passing trains and frequently breaking windows in locomotive cabs, cabooses, or passenger coaches. In addition, there have been incidents reported of persons suspending heavy objects such as cinder blocks or manhole covers from overpasses in such a manner as to strike oncoming trains. Another act of vandalism that is of growing concern is the firing of small arms weapons at passing trains.

The Federal Railroad Administration/Department of Transportation (FRA/DOT) initiated a study[1] to determine if there was a need for a Federal regulation to require the use of improved glazing materials in the windows of railroad vehicles. Opinions were solicited from various groups of interested parties including representatives of the Association of American Railroads (AAR), labor unions (United Transportation Union, Brotherhood of Railroad Locomotive Engineers), glazing manufacturers, and manufacturers of railroad equipment. It was the consensus of these groups that the glazing material, and its supporting framework, should be able to withstand the impact of the following objects without complete penetration, and without the formation of glass fragments (spall) on the inside of the window: (a) a hand-thrown, fist-sized object (half a brick, stones, railroad spikes or bolts, bottles, etc.) hurled from a distance of about 8 meters (25 feet), (b) a .22-caliber, high-velocity, long rifle projectile fired from a distance of about 92 meters (300 feet), and (c) impact against a suspended cinder block at a vehicle speed of 48 km/hr (30 mph).

As a part of this study, FRA/DOT contracted with the U.S. Army Ballistic Research Laboratory (BRL) to conduct a test program to provide data on the impact resistance of several types of glazing materials, and to develop performance criteria for protective glazing used in railroad locomotive cabs, passenger coaches, and cabooses. This program was designed to consist of the following phases or tasks: (1) literature survey, (2) projectile (bullet) impact tests, (3) suspended, heavy object (cinder block) impact tests, and (4) small, hand-thrown object impact tests. Details of performing each of these tasks are discussed in the following section.

[1] *Federal Register, Volume 42, No. 47, Thursday, March 10, 1977.*

II. DETAILS OF TESTS

A. Literature Survey

A search of the technical literature was made for the dual purpose of (a) compiling data on the perforation, spallation, or fracture of glazing materials, and (b) to obtain any available information on specific incidents from accident reports or witness accounts. It was hoped that the latter purpose would provide some useful data on the conditions that existed at the time of the reported incidents, and thus enable the testing to be performed under an environment as close to "real life" as possible.

A large portion of the literature examined was concerned with the impact damage of glazing materials (glass, plastics, and combinations thereof) as applied to the area of transparent armor. A significant amount of these reports were classified and therefore are not included here. A listing of the articles pertinent to this program are given in the Bibliography of this report.

There was only a limited amount of information obtained from the literature on specific accidents or incidents of vandalism. One source[2] presented a very detailed analysis of accidents suffered by occupants of locomotive cabs. While this report categorized 858 accidents from 1961 to 1972 (date of report), almost all of the accidents discussed were not applicable to the problem to which the current program was addressed. The accidents detailed were the result of collisions, derailments, and cab conditions. This last category included such things as the closing of doors or windows on fingers, striking protrusions in the cab, slipping on oily floors, etc. There were only a very limited number of accidents mentioned that resulted from acts of vandalism, and these were the result of rocks or similar type objects being thrown at locomotive cab windows.

Another recent summary[3] on reported incidents of vandalism was reviewed, and although only a short period of time was covered (approximately 2 months), there was a total of 877 cases. The report provided some specific information on many of the incidents, such as the location of the impacts, train speed and direction of movement, and the type of missile and method of projection. This information indicated the following general characteristics:

a. Most (86 - 90%) of the impacts against railroad equipment were reported to occur against the front and sides;

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[2]*F. Kurz, FRA-OPP-73-3, Federal Railroad Administration, Washington, D.C., September, 1972, (PB-214 129).*

[3]*Incident Report Summary, "Missile Impact upon Railroad Rolling Stock," Federal Railroad Administration, Washington, D.C., February, 1977.*

b. Most of the impacts occurred at train speeds between 32 and 64 km/hr (20-40 mph), the average speed of all incidents being 43.6 km/hr (27.1 mph);

c. Almost all (over 95%) incidents occurred during the forward motion of the train;

d. More than 98% of the incidents involved hand thrown objects or firearms.

The potential of extremely serious injury or severe damage resulting from the impact against heavy, suspended objects was considered to be of sufficient concern to warrant special consideration, even though the percentage of total incidents reported was relatively low. It was reasoned that if a glazing material was able to provide adequate protection upon impact against a heavy suspended object, protection also would likely be provided against all hand thrown objects. It was decided, therefore, to modify the test program somewhat and to concentrate efforts on the following phases:

1. Projectile impact tests, with emphasis on .22-caliber, high-velocity, long rifle projectiles. This type of projectile was the most frequently used according to reports of incidents involving the use of firearms.

2. Heavy object impact tests in which glazing materials would be evaluated for their resistance to impact against a suspended cinder block. Tests during these phases should provide data on both ends of the spectrum of objects likely to impact windows of railroad equipment. There are the small, high-velocity objects (as exemplified by .22-cal projectiles), and there are the large, bulky, relatively slow moving objects (as exemplified by cinder blocks, with the train actually doing the moving). The resistance of glazing materials to the impact of other objects would be expected to fall in between these extremes.

B. Materials

All tests were conducted on glazing materials that were available as "off the shelf" items. Initial samples of materials were provided by the Association of American Railroads (AAR). A list of the materials is given in Table I.

Company or manufacturers designations are not provided in this Table or anywhere else in this report. Letter codes were used throughout. This was done in an attempt to avoid any misinterpretation of the data as being an endorsement, or conversely, as a rejection, of any of the materials. Current tests were performed solely to evaluate existing, available materials as an aid in the development of performance criteria. The relative success or failure of any materials does not and should not be construed to indicate approval or disapproval of that material.

Table I. List of Glazing Materials Tested*

Test Material	Thickness cm	Thickness in	General Composition or Construction
A	1.27	0.50	**Safety glass** (two pieces of glass with an inner layer of resinous material).
B	1.43	0.56	Tempered glass; inner layer; tempered glass; glass spall shield.
C	1.27	0.50	Abrasion resistant polycarbonate plastic.
D	1.43	0.56	Tempered glass; polyvinylbutyl inner layer; tempered glass.
E	0.635	0.250	Abrasion resistant polycarbonate plastic.
F	1.43	0.56	Annealed glass; polyvinylbutyl inner layer; annealed glass.
G	1.43	0.56	Tempered glass; polyvinylbutyl inner layer; tempered glass.
H	1.27	0.50	Float glass; vinyl inner layer; float glass.
I	1.75	0.69	Float glass; vinyl inner layer; float glass; vinyl inner layer; float glass.
J	1.75	0.69	Heat-strengthened glass; vinyl inner layer; heat-strengthened glass; vinyl inner layer; heat-strengthened glass.
K	1.27	0.50	Glass; plastic interlayer; glass.
L	1.27	0.50	Glass; plastic interlayer; polycarbonate plastic.
M	1.43	0.56	Tempered glass; interlayer; polycarbonate; interlayer; tempered glass.
N	1.43	0.56	Tempered glass; interlayer; tempered glass.
O	1.27	0.50	Abrasion resistant polycarbonate plastic.
P	0.95	0.375	Abrasion resistant polycarbonate plastic.
Q	0.635	0.250	Abrasion resistant polycarbonate plastic.
R	1.43	0.56	Glass; inner layer; polycarbonate; inner layer; glass, thin glass spall shield.
S	1.43	0.56	Glass; inner layer; polycarbonate; inner layer; glass.
T	0.95	0.375	Abrasion resistant polycarbonate plastic.

*The size of all test samples was 73.97cm (± 0.32 cm) x 41.91 cm (± 0.32 cm); 29.125 in (± 0.125 in) x 16.5 in (± 0.125 in).

C. Projectile (Bullet) Impact Tests

Impact tests were performed on the materials listed in Table I employing .22-caliber, high-velocity, long rifle projectiles having a weight of 40 grains (2.59 grams). A drawing illustrating the set-up for these tests is shown in Figure 1.

The glazing material targets were positioned at an angle of 0° obliquity, i.e., perpendicular to the flight path of the projectile. The targets were clamped against a metal frame with a rubber gasket placed between the target and frame to serve as a cushion. The distance from the muzzle of the gun barrel to the front surface of the target was 4.80 meters (15.75 feet). The distance from the muzzle to the first velocity screen was 3.89 meters (12.75 feet). Projectile velocities were measured by means of paper screens wired to a counter timer. The screens were positioned in front of the glazing material target with an interval of 0.6096 meters (2.0 feet) between screens.

A section of aluminum having a thickness of 0.0051 cm (0.002 in) was placed 38.1 cm (15.0 in) in back of the target for each test to serve as a witness sheet. This provided an indication of the amount of spall (glass fragments) produced, if any, and the general dispersion pattern of the spall.

No high speed motion pictures were made of the projectile impact tests due to the lack of sufficient light. These tests were conducted in an indoor range and there was no space available for the number of lights that would have been required to provide adequate illumination. Still photographs were taken of the materials after completion of the tests.

Since the projectile impact tests were conducted in an indoor range, impacts from longer ranges could not be done as on an outdoor facility. Using the velocity-distance data[4] given in Table II and Figure 2, any desired range could be simulated by adjusting the powder load of the projectile to obtain a specific velocity. In this particular work the average maximum velocity of the .22-caliber ammunition was 366 meters per second (1200 feet per second). This then became the muzzle velocity, or zero distance point on the curve. (See Figure 3).

Figure 2 presents a plot of the velocity as a function of distance for any 40-grain, .22-caliber projectiles, up to a theoretical limit of 427 m/s (1400 f/s). On this curve any muzzle velocity becomes the zero distance point, and subsequent distances along the x-axis are adjusted to reflect the variation in muzzle velocity.

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[4] *M. J. Piddington, Launch and Flight Division, Ballistic Research Laboratory, private communication.*

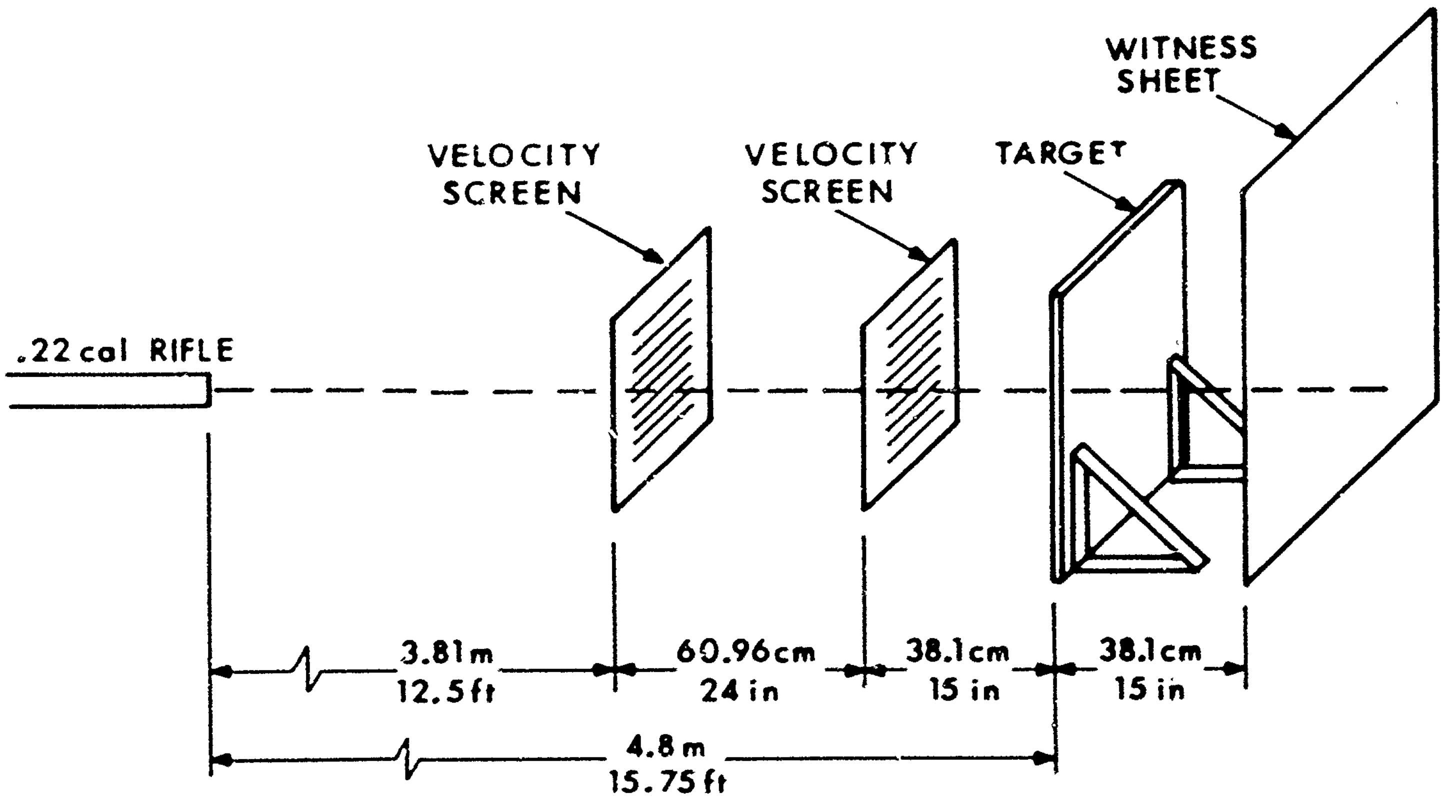


Figure 1. Diagram of Test Arrangement Used in Projectile Impact Tests

Table II. Velocity-Distance Data for 40-Grain, .22-Caliber, High-Velocity, Long Rifle Projectiles

Range			Velocity	
Meters	Yards	Feet	Meters/Second	Feet/Second
0	0	0	426.7	1400.0
100	109.4	328.1	302.5	992.5
200	218.8	656.2	252.5	828.5
300	328.2	984.3	218.2	715.9
400	437.6	1312.4	190.0	623.4
500	547.0	1640.5	165.4	542.7
600	656.4	1968.6	143.7	471.5
700	765.8	2296.7	124.6	408.8
800	875.2	2624.8	108.0	354.4
900	984.6	2952.9	93.8	307.8
1000	1094.0	3281.0	82.1	269.4
1100	1203.4	3609.1	73.0	239.5
1200	1312.8	3937.2	67.0	219.8
1300	1422.2	4265.3	64.8	212.6
*1358	1485.7	4455.6	-	-

*Max. Range

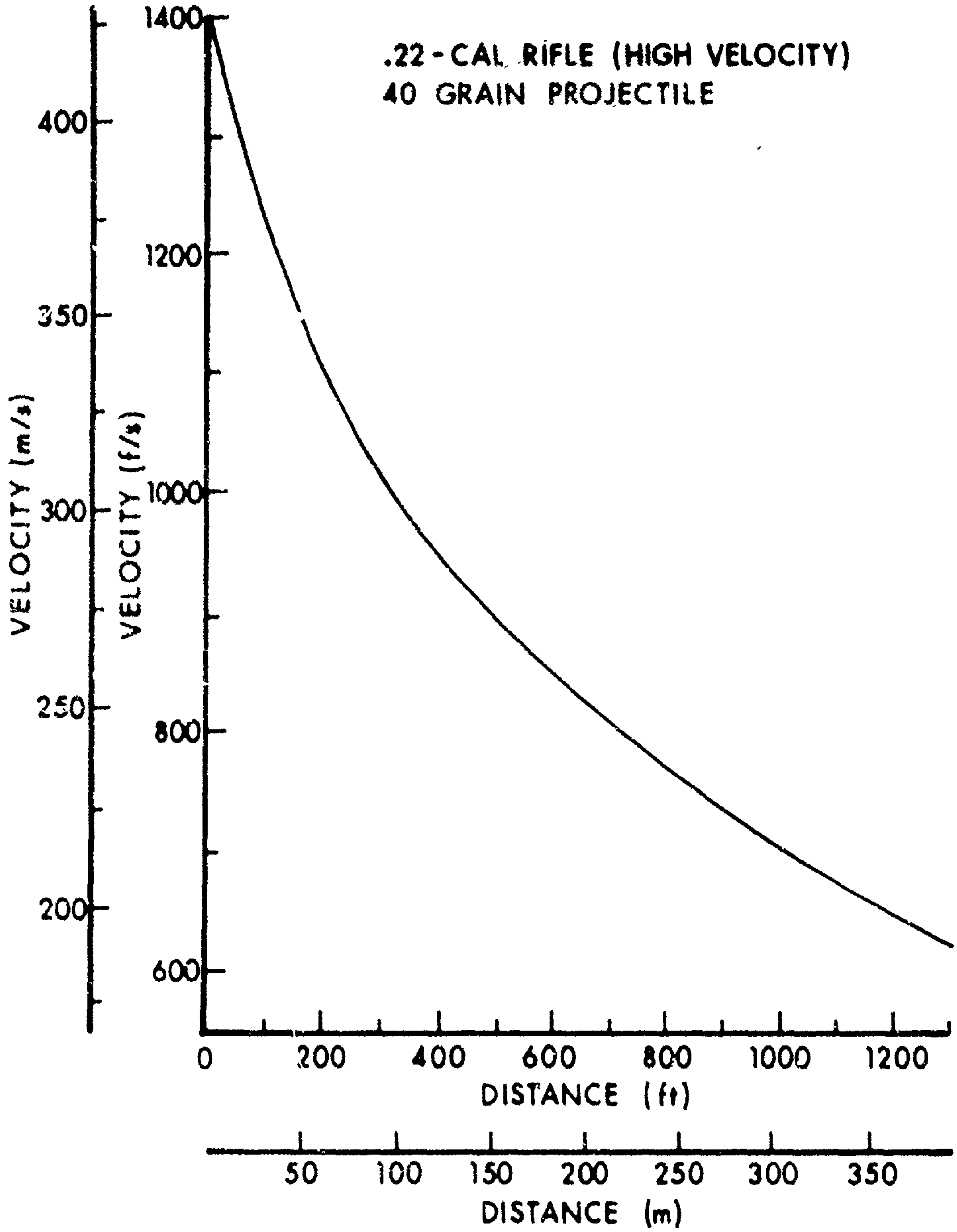


Figure 2. Velocity/Distance Curve for 40-Grain, .22-Caliber Projectiles up to a Maximum Muzzle Velocity of 1400 f/s (427 m/s)

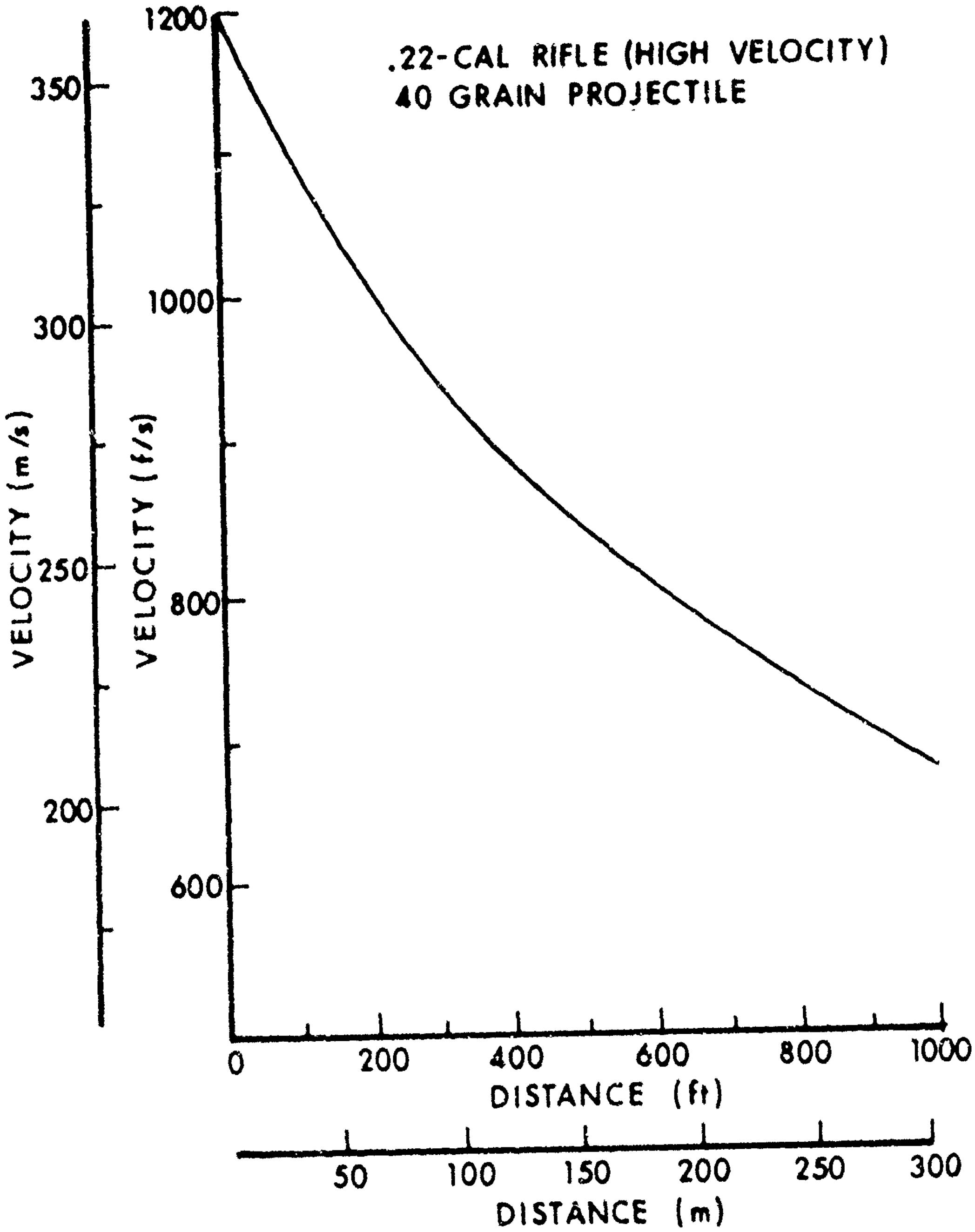


Figure 3. Velocity - Distance Curve for the 40 grain, .22 caliber Projectiles Used in this Work.

D. Heavy Object (Suspended) Impact Tests

The system employed to determine the resistance of the glazing materials when impacted against a heavy suspended object is shown in Figure 4. A frame to hold the glazing materials during the tests was fabricated and welded to the body of the truck shown. The hole in the frame was 68.6 cm x 36.8 cm (27.0 in x 14.5 in). This size opening was able to accomodate all samples of test materials and still permit approximately 2.54 cm (1.0 in) on each side of the glazing materials to be held within the frame. The front portion of the frame was removable and was held in place by several bolts during a test. This enabled the test materials to be changed with a minimum amount of effort and lost time between tests. A rubber gasket was placed around the perimeter of the opening and served as a cushion for the glazing materials in the frame.

The test course was prepared on a long, straight portion of a hard-surfaced road that also had a slight downhill slope. A line was painted on the road to provide a guide for the driver of the truck. Markers also were placed at intervals on the line to furnish additional reference points. The markers were bags filled with sand and painted with a high visibility color, and thus were not hazards in the path of the vehicle. The body of the truck cleared these markers by a substantial distance. In addition, a mark was placed on the window and hood of the truck. By aligning these points with the markers and line on the road it was possible to reasonably repeat the same path of impact for each test. (Note: After 2 practice runs, the target was impacted within a 7.6 cm (3.0 in) radius from the center for every test thereafter).

Cinder blocks were suspended from a framework fabricated from steel pipe in such a manner as to impact the center of the glazing material. The dimensions of these blocks were 20.3 cm x 20.3 cm x 40.6 cm (8.0 in x 8.0 in x 16.0 in) and they weighed 11.98 kilograms (26.4 pounds).

The blocks were oriented so that the initial point of contact against the glazing material was one of the corners. This was accomplished by tying heavy string securely around the block and then threading the string through adjustable clips. The string was positioned such that small adjustments could be made quickly to the position of the block in both a vertical and horizontal direction.

The reason for the specific positioning of the cinder blocks for impact, as opposed to a random orientation, was to examine a "worst-case" situation, and thereby reduce the need to test several impact parameters. If a material can withstand an impact against a corner of a cinder block, it should be able to survive an impact against a flat side or edge.

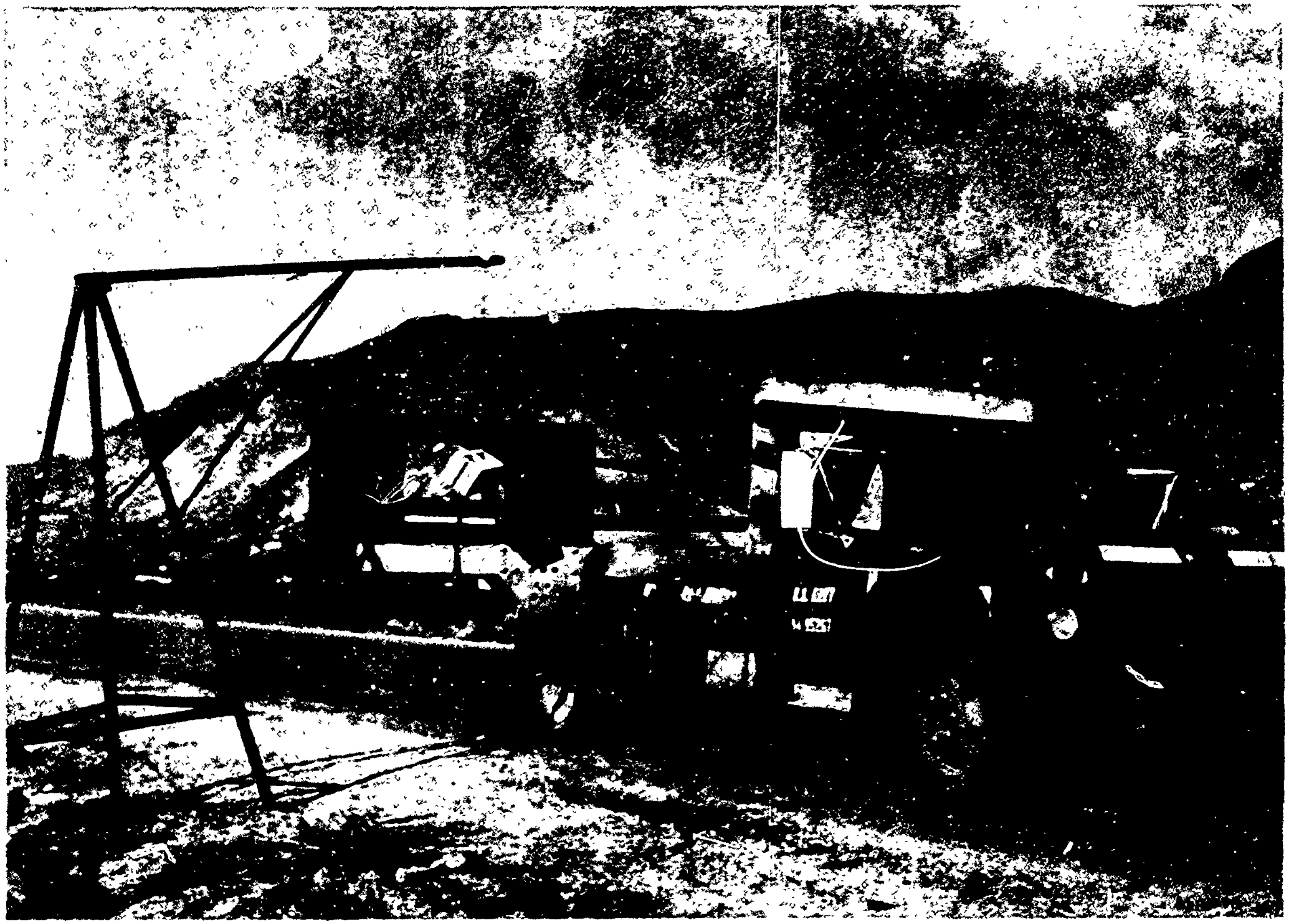


Figure 4. Test Set-up for Impact Tests Against a Suspended Cinder Block

A high-speed motion picture camera was positioned on the back of the truck (to the side and back of the framework with a view of the impact at an angle of approximately 45°) to record the damage to the glazing material. This camera was activated by the driver of the truck by means of a switch in the truck cab. There also was a high speed motion picture camera on the ground with the field of view perpendicular to the path of the vehicle. Still photographs were taken of both the front and back of the glazing material after each test.

Markers (striped poles) were installed along the test course at 15.24 meter (50.0 feet) intervals. These were positioned so that they appeared in the film of each test as viewed through the camera on the back of the truck. This enabled vehicle speeds to be calculated from the film and served to confirm the speed indicated by the speedometer of the truck. The vehicle speeds determined from the film usually varied no more than 5.6 kilometers/hour (3.5 miles/hour) from that indicated by the vehicle speedometer.

III. RESULTS AND DISCUSSION

A. Projectile (Bullet) Impact Tests

The results of the projectile impact tests against those types of glazing materials previously listed in Table I are summarized in the following table (Table III) and in Appendix B. Illustrations of typical damage are shown in Figures 5 and 6.

The damage criteria for determining the projectile impact resistance of these materials were to include the penetration and/or perforation of the target, and the production of glass fragments, or spall, from what would be the inside surface of the glazing material. Glass fragments from the front or impact surface were not considered to be a threat to personnel in this case.

It was intended originally to determine the maximum projectile velocity that the glazing material targets could withstand without having any spall (glass fragments) come off the inside surface of the target. It was expected to be able to determine this velocity to within ± 15.24 meters per second (± 50 feet per second). However, some factors were encountered during the testing program that precluded the velocity being determined that precisely for some materials.

Since there was a relatively limited supply of materials available, some samples of each needed to be saved for subsequent impact tests against objects other than small arms projectiles. Therefore, the number of projectile tests required to determine the velocity at which an unacceptable level of damage occured could not be made within the limits of ± 15.24 meters per second (± 50 feet per second). Also, upon projectile impact some materials were cracked severely, the cracks

Table III. Summary of .22-Cal Projectile Impact Tests

Test Material	Projectile Velocity m/s	Projectile Velocity f/s	Distance (Range) meters	Distance (Range) feet	Results and/or Remarks
A	219	719	259	850	No spall.
	321	1053	44	145	Moderate amount of spall.
	377	1237	5	16	Large amount of spall.
B	235	771	210	690	No spall.
	326	1069	38	125	No spall.
	373	1222	5	16	No spall.
C	122	400	680	2230	No damage.
	263	864	140	460	No spall. Slight bulge.
	280	919	107	350	No spall. Slight bulge.
	292	959	85	280	No spall. Slight bulge.
	317	1039	49	160	No spall. Projectile embedded, no complete penetration.
	381	1251	5	16	Complete penetration through target.
D	311	1021	56	185	No spall.
	378	1241	5	16	Much spall; severe cracking.
E	159	522	494	1620	No damage.
	179	587	405	1330	No damage.
	225	739	241	790	Small indentation.
	240	788	195	640	Small indentation.
	283	927	102	335	Knocked out 3.2 cm (1.25 in) hole in target.
	286	940	105	345	Knocked out 2.5 cm (1.0 in) hole in target.
	287	942	95	310	No penetration.
	306	1003	64	210	Knocked out 2.5 cm (1.0 in) hole in target.
	311	1019	58	190	Complete penetration.
	324	1064	40	130	Complete penetration.
	349	1144	5	16	Complete penetration.

Table III (cont). Summary of .22-Cal Projectile Impact Tests

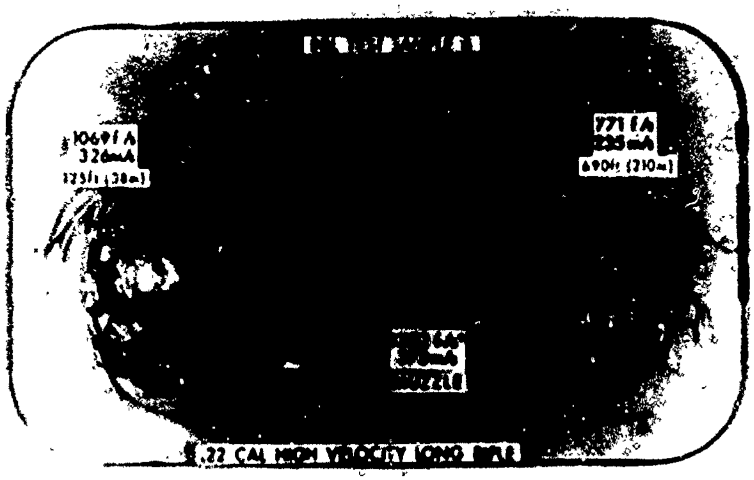
Test Material	Projectile Velocity m/s	Projectile Velocity f/s	Distance (Range) meters	Distance (Range) feet	Results and/or Remarks
F	234	766	213	700	No spall; slight cracking.
	313	1025	55	180	Light to moderate spall.
	314	1028	53	175	Considerable spall.
	342	1123	5	16	Large amount of spall.
	358	1174	5	16	Large amount of spall.
G	284	930	101	330	No spall; severe cracking.
	318	1044	47	155	No spall.
	353	1159	5	16	Very large amount of spall.
H	304	999	67	220	Slight amount of spall.
	366	1200	5	16	Large amount of spall.
I	342	1123	5	16	No spall.
	380	1248	5	16	No spall.
J	197	647	335	1100	No spall.
	310	1019	56	185	Very slight amount of spall.
	316	1037	50	165	No spall.
	359	1179	5	16	Moderate to severe spall.
K	180	590	405	1330	No spall.
	203	666	314	1030	Slight amount of spall.
	294	963	84	275	Large amount of spall.
	365	1199	5	16	Large amount of spall.
L	205	673	306	1005	No spall.
	345	1133	5	16	No spall.
M	216	709	268	880	No spall.
	319	1046	47	155	No spall.
	354	1163	5	16	Large amount of spall.
	381	1250	5	16	Very large amount of spall.

Table III (cont). Summary of .22-Cal Projectile Impact Tests

Test Material	Projectile Velocity m/s	f/s	Distance (Range) meters	feet	Results and/or Remarks
N	213	699	279	915	No spall.
	327	1074	37	120	Large amount of spall.
	361	1186	5	16	Large amount of spall.
O	339	1113	24	80	Bulge in back of target but no complete penetration. No spall.
	345	1132	18	60	Large bulge on back of target but no complete penetration. No spall.
	372**	1221**	15	50	Bulge in back of target and crack in bulge. No complete penetration. No spall.
	394**	1293**	6	20	Complete penetration through target plate.
P	313**	1026**	91.4	300	Bulge in target and crack in bulge. Appeared to be right at or very close to limit; no test made at other ranges.
Q	301	989	70.1	230	Bulged back of target; no cracking; no spall.
	307	1006	62.5	205	Bulge in back of target and bulge was cracked.
	307	1008	61.0	200	Complete penetration.
R	Material not tested; insufficient number of samples.				
S	Material not tested; insufficient number of samples.				
T	323*	1060*	46	150	Bulge in back of target; slight crack in bulge. No penetration.
	336*	1102*	31	100	Complete penetration.

*Average of 5 tests.

**Projectiles with high muzzle velocity were used. Data is the average of a minimum of six tests. Distances given were measured.



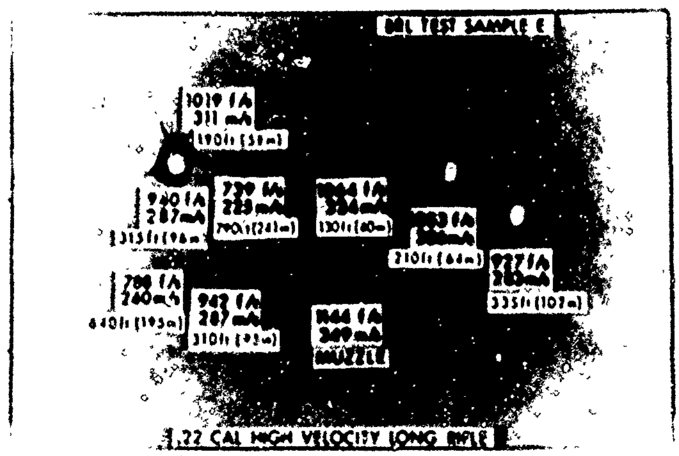


Figure 5. Example of Typical Impact Damage from Projectile Impacts.

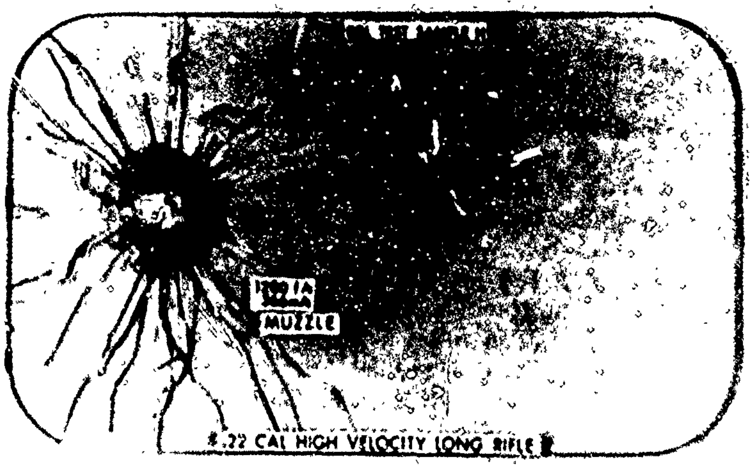


Figure 6. Example of Typical Impact Damage from Projectile Impacts.

extending over large, widespread areas of the target. These samples thus could not be used for multiple impacts. On the other hand, some materials did not experience much widespread damage, and therefore the same samples could be rotated and used for several additional tests.

For these reasons it was decided to modify the test program somewhat. Instead of determining the velocity for the onset of unacceptable damage within the limits given above, the materials were evaluated with respect to their capability to withstand the impact of a .22-caliber, 40-grain projectile fired from a distance of 91.44 meters (300 feet), a property previously mentioned as being desired in a glazing material.

From Figures 2 or 3 the velocity of this type projectile fired from this distance is indicated to be approximately 290 meters per second (950 feet per second), based upon a muzzle velocity of 366 m/s (1200 f/s). As before, this velocity was achieved by adjusting the propellant load in the cartridge. Tests were conducted in the same indoor range described previously. Depending upon the results and the factors discussed above (degree of damage, availability of samples), some additional tests were made, where possible, in an attempt to determine more accurately the damage velocity.

Those tests indicated as being made from an equivalent distance or range of 5 meters (16 feet) were conducted with projectiles whose propellant load (powder charge) was not modified. The cartridges were used directly as received. These were considered to be at muzzle velocity.

The results indicate that Material A had a moderate amount of spall produced off the back surface of the target when impacted at a velocity of 321 m/s (1053 f/s). This would be equivalent to a distance of approximately 44 meters (145 feet). No spall was produced at an impact velocity of 219 m/s (719 f/s), but there were no samples of the material available at this time to conduct additional tests at any intermediate impact velocities.

Material B was found to provide very good resistance to projectile impact. No spall was produced, even from the impacts of projectiles fired from 5 meters (16 feet) away. Material I and Material L were similar in that they too did not have any spall come off the back surface of the target materials from the impact of projectiles fired from a distance of 5 meters (16 feet).

Material C, a polycarbonate plastic, provided good impact resistance up to a projectile velocity of 317 m/s (1039 f/s). At this velocity and equivalent distance (49 meters, 160 feet) the .22-caliber projectile was embedded in the target, but there was no penetration completely through the material. At a muzzle velocity of 381 m/s (1251 f/s), from a distance of 5 meters (16 feet), a projectile passed completely through the material. No attempt was made at this time to determine more

precisely the point at which a projectile would just pass through the material.

Examination of the impact area for the test of a projectile fired at 311 m/s (1021 f/s), an equivalent distance of 56 meters (185 feet), against Material D indicated that no spall was produced. The degree of damage was such that it is likely that the velocity of the projectile could be increased, with a corresponding decrease in the equivalent distance, without significantly changing the amount of damage. How much more than this velocity was not determined at this time because of the limited number of test samples available.

Some different type results were noted during the projectile impact tests against Material E. At projectile velocities decreasing from 349 m/s to 311 m/s (1144 f/s to 1019 f/s) complete penetration through the material was affected, a clean, neat hole being produced. At a range of velocities from 306 m/s to 283 m/s (1003 f/s to 927 f/s), there were 2.5 cm to 3.2 cm holes (1.0 in to 1.25 in) put into the material. Actually, a "plug" of material was knocked out of the target. At a velocity of 240 m/s (788 f/s) and lower there was no appreciable damage produced. It appeared that the damage threshold for this material, when impacted by .22-caliber projectiles, lay between 240 and 283 m/s (788 - 927 f/s). This corresponds to an approximate equivalent distance of 195 to 102 meters (640 to 335 feet). No attempt was made at this time to determine more precisely the damage threshold for Material E.

Material F had light to moderate spall produced from an impact velocity of 313 m/s (1025 f/s), an equivalent distance of 55 meters (180 feet). Material H had spall, even though termed slight, produced from a projectile impact velocity of 304 m/s (999 f/s), and equivalent distance of 67 meters (220 feet). Material K also had spall produced from the back surface from a projectile with an impact velocity of 294 m/s (963 f/s), an equivalent distance of 84 meters (275 feet).

Material G did not have any spall produced from a projectile impact velocity of 318 m/s (1044 f/s), an equivalent distance of 47 meters (155 feet). However, there was a very large amount of spall produced from an impact velocity of 353 m/s (1159 f/s) from a distance of 5 meters (16 feet). No attempt was made at this time to determine more accurately the velocity and corresponding distance where "damage-no damage" occurred. Material M was very similar to Material G in performance at very nearly identical velocities.

In order to determine the resistance to projectile impact of Material J with more certainty some additonal tests would be required. During the current program there was no spall produced from a projectile impact at 316 m/s (1037 f/s). There was a very slight amount of spall produced from a projectile impact at a velocity of 310 m/s (1019 f/s). Normally one would expect less damage from an impact at a lower velocity. Should these impact velocities be at or near the threshold damage point,

however, as it appeared they might be, this type of variation could be expected to occur. More projectile impact tests are needed to resolve this variation, but these were not made at this time because of an insufficient number of test samples.

Also, additional tests would be necessary to determine with more assurance the impact resistance of Material N. No tests were made between velocities of 327 m/s and 213 m/s (1074 f/s and 699 f/s). These correspond to equivalent distances of 37 meters and 279 meters (120 feet and 915 feet), respectively. As before, the limited number of samples of this material precluded more tests being performed at this time.

Materials O and P were tested with 40-grain, .22-caliber projectiles that had a higher muzzle velocity than 366 meters/second (1200 feet/second). For the tests on these materials, conducted on an outdoor facility, actual distances were measured between the gun and target.

At a distance of 15.2 meters (50 feet) and at an impact velocity of 372 m/s (1221 f/s), there was a bulge in the back of the target. The bulge was cracked (split), but there was no spall and no complete penetration. At a distance of 6 meters (20 feet), there was complete penetration through the material at an impact velocity of 394 m/s (1293 f/s). No tests were conducted at any distances or velocities between those given for material O.

Material P was impacted by .22-caliber projectiles fired from a measured distance of 91.4 meters (300 feet). The average impact velocity was 313 m/s (1026 f/s). At this velocity and distance, although there was a bulge in the target and this bulge was cracked or split, there was no complete penetration of the target. The degree of damage, however, indicated that this was at, or very near, the ballistic limit, and that a relatively small increase in velocity would produce complete penetration of the target material. Therefore, no other tests were conducted on this material at shorter distances, with the resultant increase in impact velocity.

Projectile impact tests conducted against Material Q indicated a narrow range in the impact velocity that separated the area of complete penetration from that where no complete penetration was achieved. As indicated in Table III, at an impact velocity of 306.6 m/s (307 m/s. 1006 f/s), there was a bulge in the back of the target material and even though the bulge was cracked there was no complete penetration. At an impact velocity of 307.2 m/s (307 m/s, 1008 f/s), there was complete penetration through the target material. Lower impact velocities did not produce any complete penetrations; all higher velocities resulted in complete penetration of the target (see Appendix B, Test Material Q).

Materials R and S were not tested for resistance to the impact of .22-caliber projectiles at this time because of an insufficient number of samples being available. These materials were tested only for resistance to impact against suspended cinder blocks.

Material T was not able to be completely penetrated by a .22-caliber projectile at an impact velocity of 323 m/s (1060 f/s). Complete penetration of this material was produced at an impact velocity of 336 m/s (1102 f/s). No tests were conducted at any intermediate velocities.

In summary, all projectile impact resistance determinations discussed above were based on tests of 40-grain, .22-caliber projectiles fired at various velocities, and corresponding equivalent distances, against the different types of glazing materials available at the time of the tests. The sole criterion employed at this time, and upon which the results were based, was whether or not any spall (glass fragments) was produced off the back side (inside surface) of the material when impacted by a .22-caliber projectile fired from an equivalent distance of no more than 91.4 meters (300 feet). No consideration was given to the amount of cracking experienced on impact, any spall produced from the front or impact surface, or what effect the degree of cracking had on visibility through the material. Also, no consideration was given to the relative costs of the materials, their availability, time required for delivery, or any other property. It is recognized, however, that eventually these factors will have to be taken into careful consideration.

B. Heavy Object (Suspended) Impact Tests

Impact tests against a heavy, suspended object, in this case a cinder block weighing 12.0 kilograms (26.4 lbs), were conducted according to the method described previously. Results of these tests are given in Table IV. Illustrations of typical types and degrees of damage are shown in Figures 7 and 8.

The damage criterion for determining the resistance of the glazing materials to impact against a suspended cinder block was essentially the same as that employed for the projectile impact tests, i.e., whether or not any glass fragments (spall) were produced off the inside surface (back side, or surface opposite the impact side) of the material, or whether or not any penetration occurred, either of which might be considered to pose a hazard to personnel. No other factor was considered at this time. Materials that were able to resist an impact against a cinder block at a minimum speed of 48 km/hr (30 mph) without having any spall come off the inside surface were considered to have demonstrated an acceptable level of impact resistance.

When Material A was impacted at 64.4 km/hr (40 mph) against a suspended cinder block, it appeared that the entire block passed through the material intact, struck the brace for the frame, and broke apart

Table IV. Summary of Heavy Object (Cinder Block) Impact Tests

Test Material	Impact Velocity				Impact Energy		Results/Remarks
	mph	km/hr	ft/sec	m/s	joules	ft-lbs	
A	10	16.1	14.7	4.5	122	90	Very little spall.
	20	32.2	29.3	8.9	476	351	Considerable spall.
	40	64.4	58.7	17.9	1923	1418	Complete penetration (whole block).
B	30	48.3	44.0	13.4	1078	795	No spall.
	40	64.4	58.7	17.9	1923	1418	Very small amount of spall.
	60	96.5	88.0	26.8	4311	3179	Considerable spall.
C	60	96.5	88.0	26.8	4311	3179	No spall.
D	40	64.4	58.7	17.9	1923	1418	No spall.
	50	80.5	73.4	22.4	3012	2221	No spall.
	60	96.5	88.0	26.8	4311	3179	Considerable spall.
E	50	80.5	73.4	22.4	3012	2221	No spall.
F	10	16.1	14.7	4.5	122	90	No spall.
	20	32.2	29.3	8.9	476	351	Considerable to moderate spall.
	40	64.4	58.7	17.9	1923	1418	Very large amount of spall.
G	30	48.3	44.0	13.4	1078	795	No spall.
	40	64.4	58.7	17.9	1923	1418	No spall.
H	10	16.1	14.7	4.5	122	90	Moderate spall.
	20	32.2	29.3	8.9	476	351	Considerable spall.
I	20	32.2	29.3	8.9	476	351	No spall.
	30	48.3	44.0	13.4	1078	795	Slight spall.
	40	64.4	58.7	17.9	1923	1418	Very little spall.
J	10	16.1	14.7	4.5	122	90	No spall.
	20	32.2	29.3	8.9	476	351	Considerable spall.
	40	64.4	58.7	17.9	1923	1418	Large amount spall.
K	50	80.5	73.4	22.4	3012	2221	No spall.
	60	96.5	88.0	26.8	4311	3179	Very little spall.
L	60	96.5	99.0	26.8	4311	3179	No spall.
M	20	32.2	29.3	8.9	476	351	No spall.
	30	48.3	44.0	13.4	1078	795	No spall.
	40	64.4	58.7	17.9	1923	1418	Severe spall.

Table IV (cont). Summary of Heavy Object (Cinder Block) Impact Tests

Test Material	Impact Velocity mph	km/hr	ft/sec	m/s	Impact Energy joules	ft-lbs	Results/Remarks
N	30	48.3	44.0	13.4	1078	795	No spall.
	40	64.4	58.7	17.9	1923	1418	Small amount of spall.
O	50	80.5	73.4	22.4	3012	2221	No spall.
P	*	*	*	*	*	*	*
Q	40	64.4	58.7	17.9	1923	1418	Slight indentation from corner of the block; no spall; no penetration.
R	40	64.4	58.7	17.9	1923	1418	Little or no spall.
	50	80.5	73.4	22.4	3012	2221	Little or no spall. About same as above.
	60	96.5	88.0	26.8	4311	3179	Little or no spall. Little or no difference between this and test at 40 or 50 mph.
S	60	96.5	88.0	26.8	4311	3179	Severe spall.
	40	64.4	58.7	17.9	1923	1418	Severe cracking and spall.
	30	48.3	44.0	13.4	1078	795	Spall produced; not as much as at 40 mph but still produced.
T	*	*	*	*	*	*	*

*Not tested.

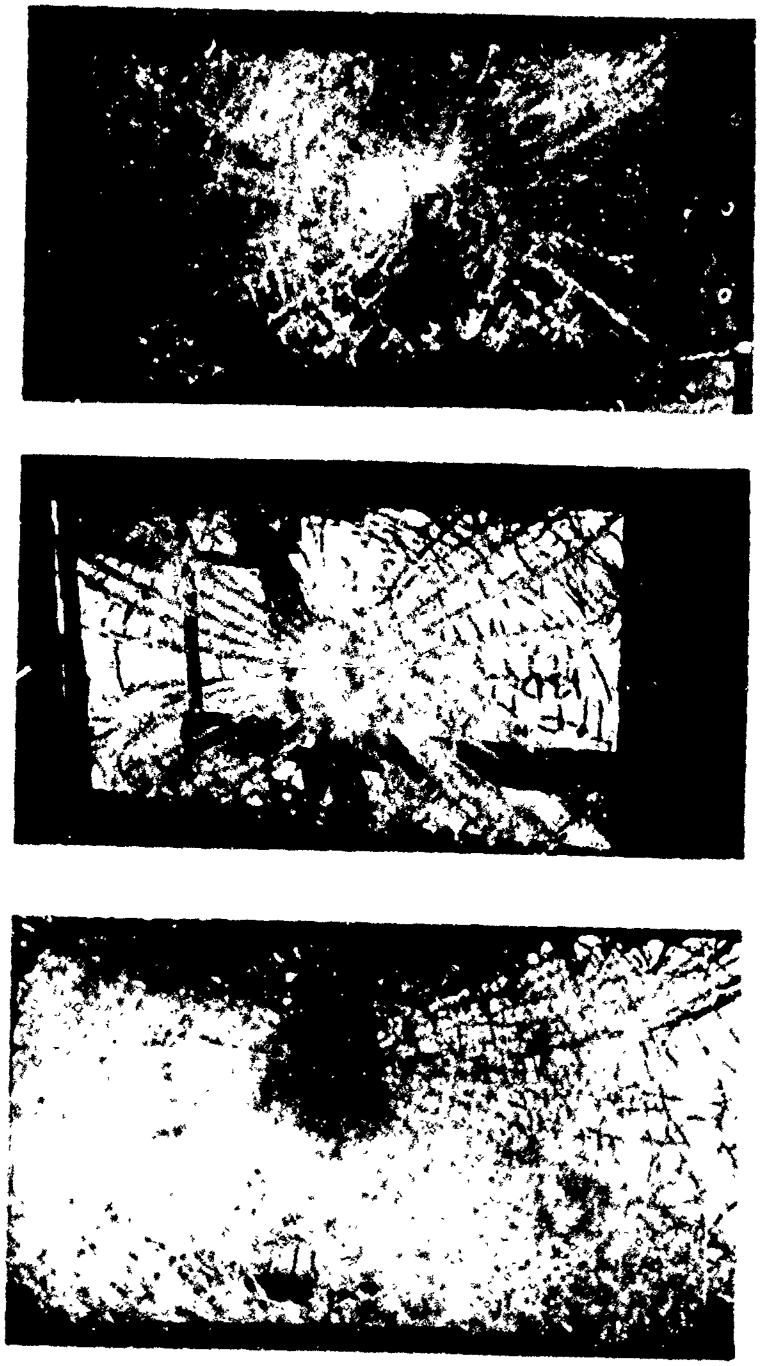


Figure 7. Example of Typical Damage from Impacts Against a Suspended Cinder Block.

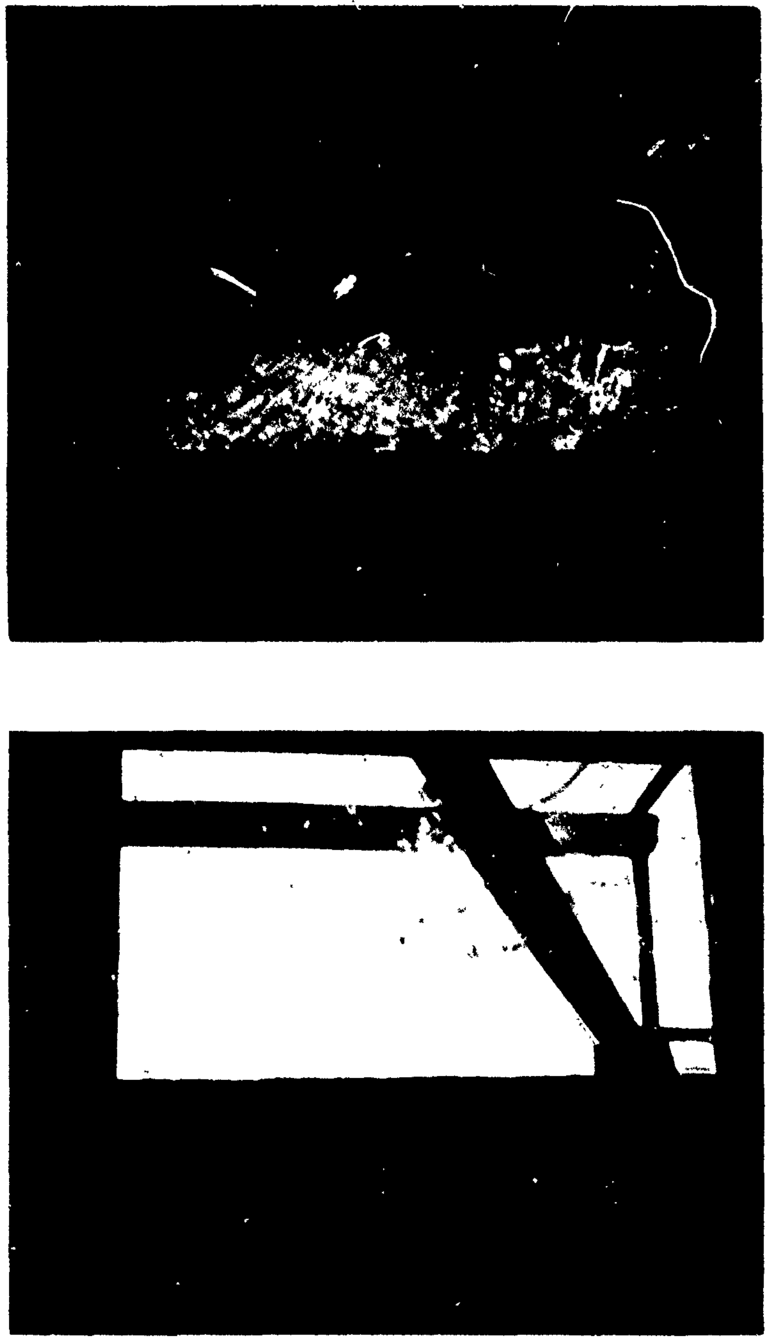


Figure 8. Example of Typical Damage from Impacts Against a Suspended Cinder Block.

when it fell onto the roadway. This was confirmed upon analysis of the high-speed motion picture films. This was by far the most severe damage experienced by any of the glazing materials during the heavy object impact tests.

C. Railroad Spike Impact Tests

In order to obtain some additional information on the impact resistance of these glazing materials, it was decided to suspend a railroad spike in place of the cinder block. This was to provide data for an object commonly found along railroad lines and likely to be thrown at passing railroad vehicles. All other components of the test system remained as before.

A spike, weighing 0.26 Kg (9 oz) and retrieved along railroad tracks at Aberdeen Proving Ground, was suspended in such a manner so as to impact against the glazing material point first (see Figure 9). This was considered to be a "worst case" type of impact. The truck holding a sample of glazing material was driven so that the material impacted against the point of the spike at 80.5 km/hr (50 mph, 24.4 m/s, 73.4 f/s). The impact speed was chosen arbitrarily as being typical of what an average person would be able to achieve if he was to throw a similar size object.

The results of the impact tests against a suspended spike are given in Table V. Typical types of damage sustained by the glazing materials upon impact against a suspended spike are illustrated in Figures 10 and 11. As noted, all tests were made at an impact speed of 80.5 km/hr (50 mph). Materials whose resistance to impact against a cinder block was exceptionally good were not tested here. It seemed reasonable to assume that these materials also would be satisfactory in a less severe situation, as this instance certainly would be. Also, in some cases where no data is given, samples of the materials were not available, supplies having been exhausted for the projectile and cinder block tests.

D. Performance Criteria/Proposed Performance Specification

Based primarily upon the results of the previously discussed projectile and cinder block impact tests, some performance criteria for evaluating glazing materials for possible use in railroad equipment were incorporated into a performance specification, a copy of which is presented in Appendix A of this report. It should be emphasized that at this time this specification is just a proposed guideline and is not to be considered as being final. A previously stated objective of this work was to develop performance criteria for protective glazing used in railroad vehicles. This specification was formulated toward meeting this objective.

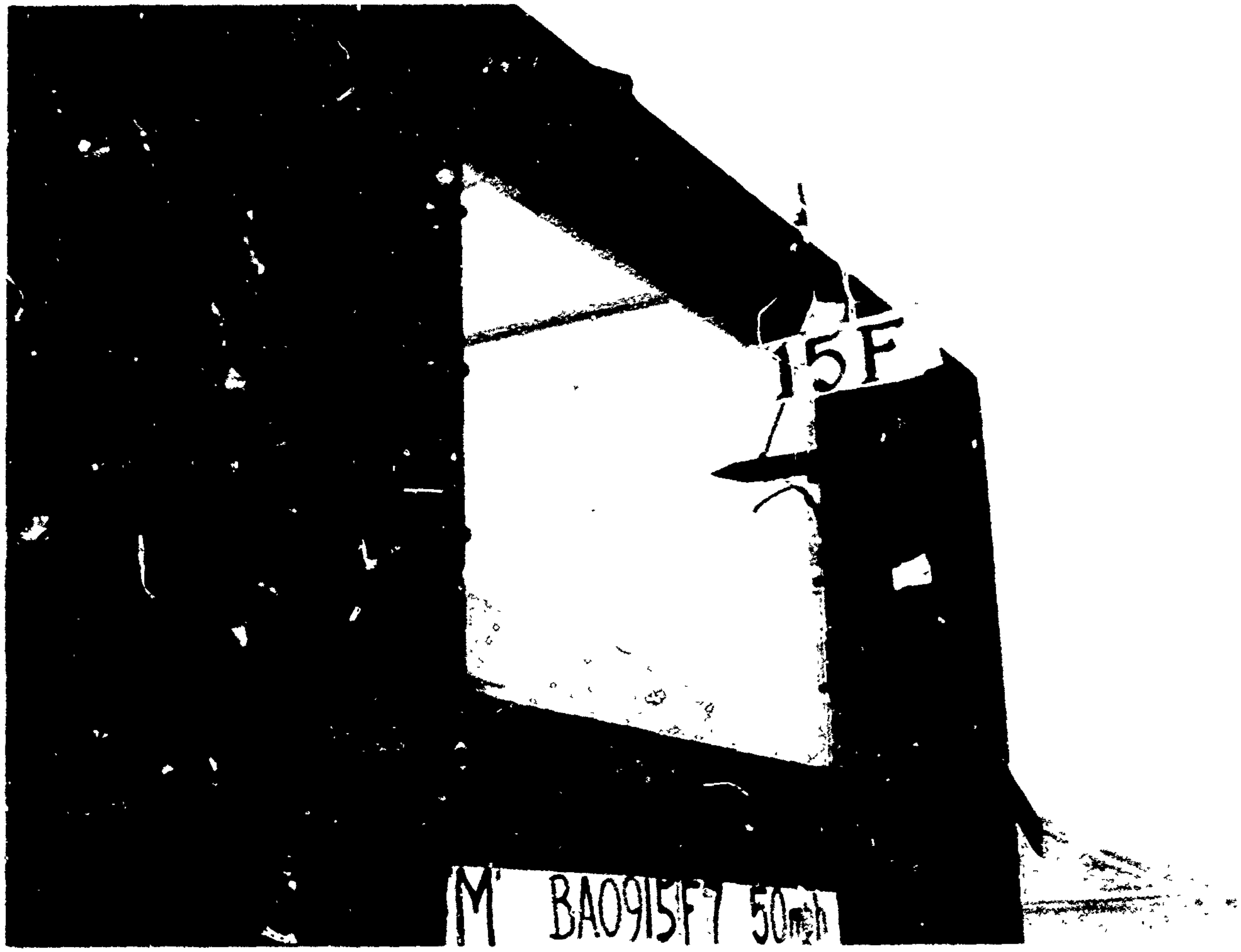


Figure 9. Test Set-up for Impact Tests Against a Suspended Railroad Spike

Table V. Summary of Railroad Spike Impact Tests*

Test Material	Results and/or Remarks
A	Moderate cracking and spall.
B	**
C	**
D	No damage.
E	No damage.
F	Moderate spall; penetration (small hole).
G	***
H	Large amount of spall; spike embedded in material.
I	Slight cracking but no spall.
J	Slight-moderate spall.
K	No spall.
L	**
M	No spall.
N	No spall.
O	**

*All tests at 80.5 km/hr (50 mph).

**Not tested. Note: Materials P, Q, R, S, and T also were not tested.

***No sample available.

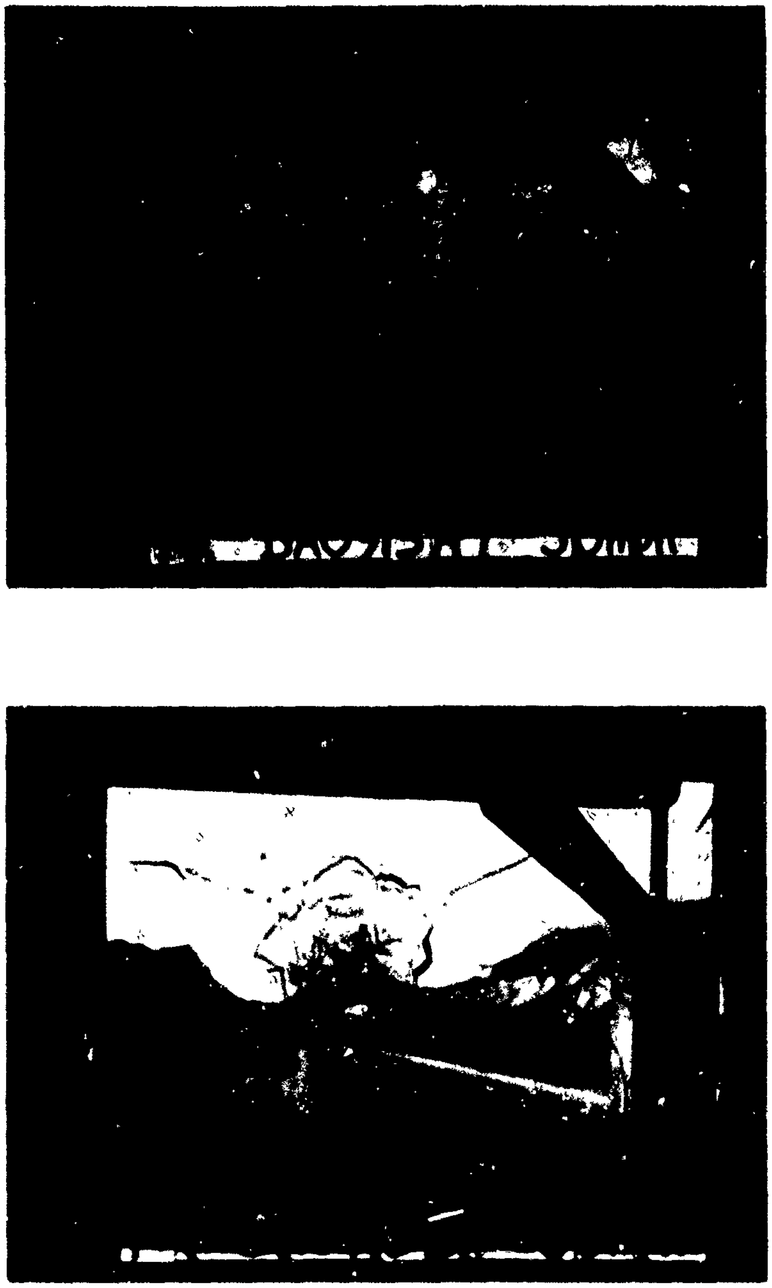


Figure 10. Example of Typical Damage from Impacts Against a Suspended Railroad Spike.

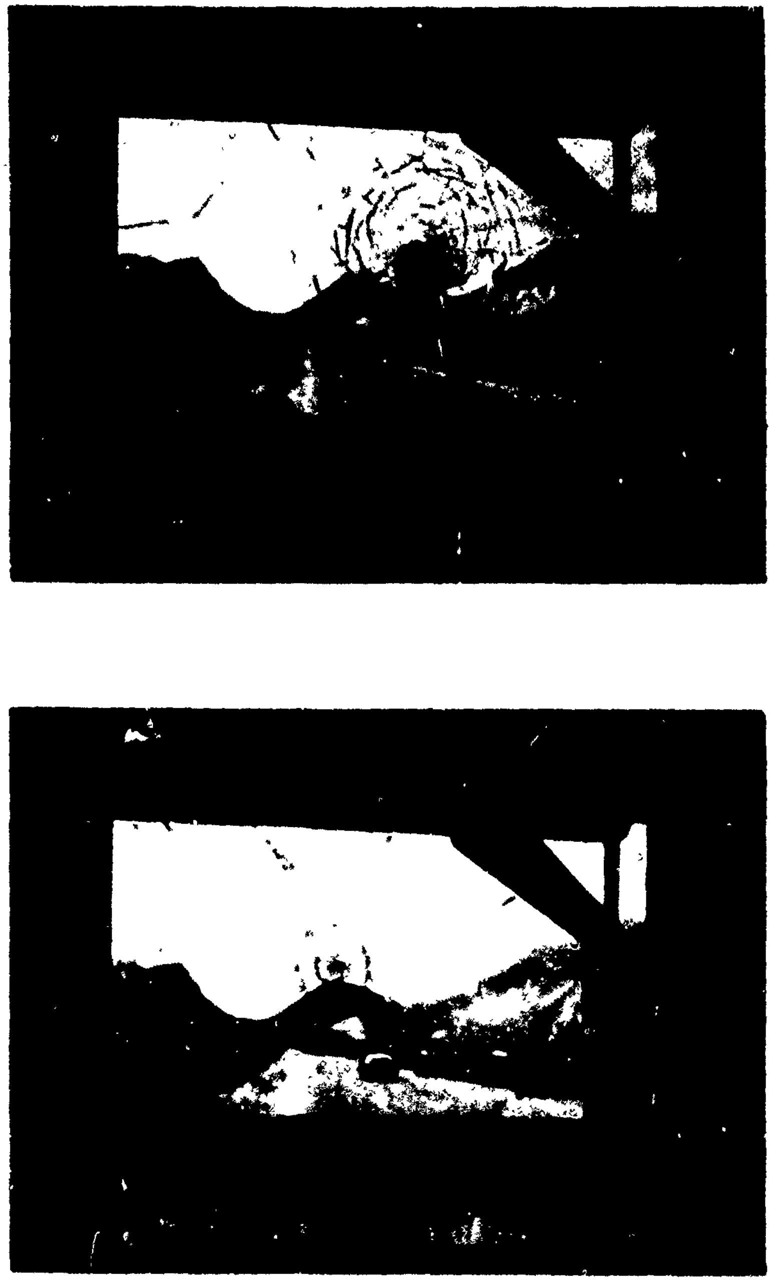


Figure 11. Example of Typical Damage from Impacts Against a Suspended Railroad Spike.

Briefly, the performance criteria suggested as having to be met are these. For front-facing windows (windshields), the glazing materials should be able to withstand the following threats:

a. the impact of 40-grain, .22-caliber projectiles at a minimum velocity of 290 meters/second (950 feet/second), which is equivalent to a maximum range of 91.4 meters (300 feet), based upon a muzzle velocity of 366 meters/second (1200 feet/second);

b. impact against a corner of a suspended cinder block (minimum weight of 10.9 Kg (24.0 lb)) at a minimum vehicle speed of 48 km/hr (30 mph; 13.4 m/s; 44.0 f/s). To be considered as having successfully withstood these impacts the back surface of the glazing material should not be penetrated and there should not be any glass fragments or spall of sufficient size and velocity to penetrate the prescribed witness plate (0.0051 cm (0.002 in) thick aluminum).

In the case of side-facing windows the same threats should be successfully defeated, except that the minimum vehicle speed for impact against a corner of a suspended cinder block should be 32 km/hr (20 mph; 8.8 m/s; 29.3 f/s) instead of 48 km/hr. As for the front-facing windows, there should be no penetration of the back surface and no penetration of the aluminum witness plate.

Table VI presents a summary of the current projectile and cinder block impact tests. Included is the minimum projectile impact velocity and the minimum vehicle impact speed at which these materials would comply with the proposed performance specification.

E. Correlation of Projectile Impact Data

All projectile impact tests discussed up to this point in this report have been of 40-grain, .22-caliber, high-velocity, long rifle projectiles fired at various velocities (with corresponding equivalent distances) against the different types of glazing materials. Since there are several other types of small arms projectiles available, it was desired to correlate the impact damage of 40-grain, .22-caliber projectiles with the impact damage from other types of small arms projectiles. Table VII presents a comparison of the characteristics of some common types of small arms ammunition.

In this work the basis of the correlation of results from various types of small arms projectiles was the amount of energy deposited at impact per area of the impact surface. Impact area was calculated as the cross-sectional area of the projectile. The slight variations in the nose geometry of the different projectiles was not considered here. It was reasoned that this still would provide a sufficiently accurate comparison without requiring more elaborate calculations to be made.

Table VI. Summary of the Results of the Projectile and Cinder Block Impact Tests

Test Material	Minimum Protection Limits: .22-Cal Projectile m/s	.22-Cal Projectile f/s	Cinder Block km/hr	Cinder Block mph	Compliance with both Criteria of Proposed Performance Spec.: Front	Side
A	220	720	16	10		
B	370	1220	48	30	X	X
C	315	1040	97	60	X	X
D	310	1020	80	50	X	X
E	240	790	80	50		
F	235	770	16	10		
G	320	1045	64	40	X	X
H	275	900	16	10		
I	380	1250	32	20		X
J	315	1040	16	10		
K	205	670	80	50		
L	345	1135	97	60	X	X
M	320	1050	48	30	X	X
N	215	700	48	30		
O	370	1220	80	50	X	X
P	310	1025	*	*	X	X
Q	305	1005	64	40	X	X
R	*	*	64	40	X**	X**
S	*	*	<48	<30		
T	323	1060	*	*	X**	X**

*Not tested; no material available.

**Estimated compliance based on results and observations experienced with other materials.

Table VII. Comparison of Characteristics of Small-Arms Projectiles

Projectile Type, caliber	.22	.30-06	.38	.44	.45	.30-06
Projectile Weight, grains	40	130	158	240	230	180
Projectile Weight, Kilograms	0.002592	0.008424	0.010238	0.015552	0.014904	0.011664
Muzzle Velocity, m/s (f/s)	366 (1200)	823 (2700)	261 (855)	448 (1470)	265 (870)	823 (2700)
Projectile Diameter, cm (in)	0.561 (0.221)	0.785 (0.309)	0.907 (0.357)	1.090 (0.429)	1.148 (0.452)	0.782 (0.308)
Projectile Impact Area, cm^2 (in^2)	0.248 (0.038)	0.484 (0.075)	0.646 (0.100)	0.933 (0.145)	1.035 (0.160)	0.481 (0.075)
Impact Energy @ Muzzle velocity, joules (ft-lbs)	174 (128)	2853 (2104)	349 (257)	1561 (1151)	523 (386)	3950 (2914)
Impact Energy/Area @ Muzzle velocity, joules/cm^2 (ft-lbs/in^2)	702 (3368)	5895 (28,053)	540 (2570)	1673 (7938)	505 (2413)	8212 (38,853)

Energy of the projectiles at impact was calculated equal to $1/2mv^2$, where m is the mass of the projectile in kilograms and v is the velocity in meters per second. Units of energy were in joules, which can be converted to foot-pounds by multiplying by 0.7376.

Table VIII presents the impact energy per area for the previously given types of projectiles over a range of velocities. These values are plotted as shown in Figures 12 and 12a.

The velocities of the projectiles listed in Table VII that would be required to produce an equivalent amount of damage as that produced by a .22-caliber projectile at some specific impact velocity were calculated and are given in Table IX. Calculations were based on the equation

$$\frac{\frac{1}{2} m_{22} v_{22}^2}{A_{22}} = \frac{\frac{1}{2} m_x v_x^2}{A_x}$$

where, m_{22} = mass of .22-caliber projectile, Kg

v_{22} = velocity of .22-caliber projectile, m/s

A_{22} = impact area of .22-caliber projectile, cm^2

m_x = mass of the projectile of interest, Kg

v_x = velocity of the projectile of interest, m/s

A_x = impact area of the projectile of interest, cm^2.

The left-hand term is the impact energy per area of .22-caliber projectiles, the value of which can be determined from Table VIII, or Figure 12 or 12a. The values of m_x and A_x are given in Table VII. The equivalent damage velocity therefore can be calculated by solving for v_x.

As an example, from Table VIII, it is indicated that a 40-grain .22-caliber projectile with an impact velocity of 305 m/s (1000 f/s) would have an impact energy intensity of 486 joules/cm^2 (2340 ft-lbs/in^2). For an equivalent amount of impact energy per unit area, and an equivalent degree of damage, the following would be required:

a. a 130-grain .30-06-caliber projectile at 236 m/s (775 f/s);

b. a 158-grain .30-caliber projectile at 248 m/s (813 f/s);

c. a 240-grain .44-caliber projectile at 241 m/s (792 f/s);

d. a 230-grain .45-caliber projectile at 260 m/s (852 f/s);

e. a 180-grain .30-06-caliber projectile at 200 m/s (657 f/s).

Table VIII. Impact Energy per Unit Area for Small-Arms Projectiles

Projectile Velocity		IMPACT ENERGY											
		.22		.30-06 (130)		.38		.44		.45		.30-06 (180)	
m/s	f/s	joules/cm^2	ft-lbs/in^2	joules/cm^2	ft-lbs/in^2	joules/cm^2	ft-lbs/in^2	joules/cm^2	ft-lbs/in^2	joules/cm^2	ft-lbs/in^2	joules/cm^2	ft-lbs/in^2
427	1400	953	4587	1587	7553	-	-	1520	7212	-	-	2211	10,458
396	1300	819	3945	1365	6496	-	-	1307	6203	-	-	1901	8994
366	1200	700	3370	1166	5549	-	-	1116	5299	-	-	1624	7683
335	1100	586	2823	977	4649	-	-	935	4439	-	-	1361	6437
305	1000	486	2340	810	3853	-	-	775	3680	-	-	1128	5336
290	950	440	2116	732	3484	-	-	701	3327	-	-	1020	4824
274	900	392	1867	653	3110	-	-	626	2970	-	-	910	4306
265	870	367	1767	611	2909	-	-	585	2778	506	2412	851	4028
261	855	356	1714	593	2822	540	2572	568	2695	490	2340	826	3907
244	800	311	1498	518	2466	472	2248	496	2355	429	2045	722	3415
213	700	237	1141	395	1879	360	1713	378	1795	327	1559	550	2602

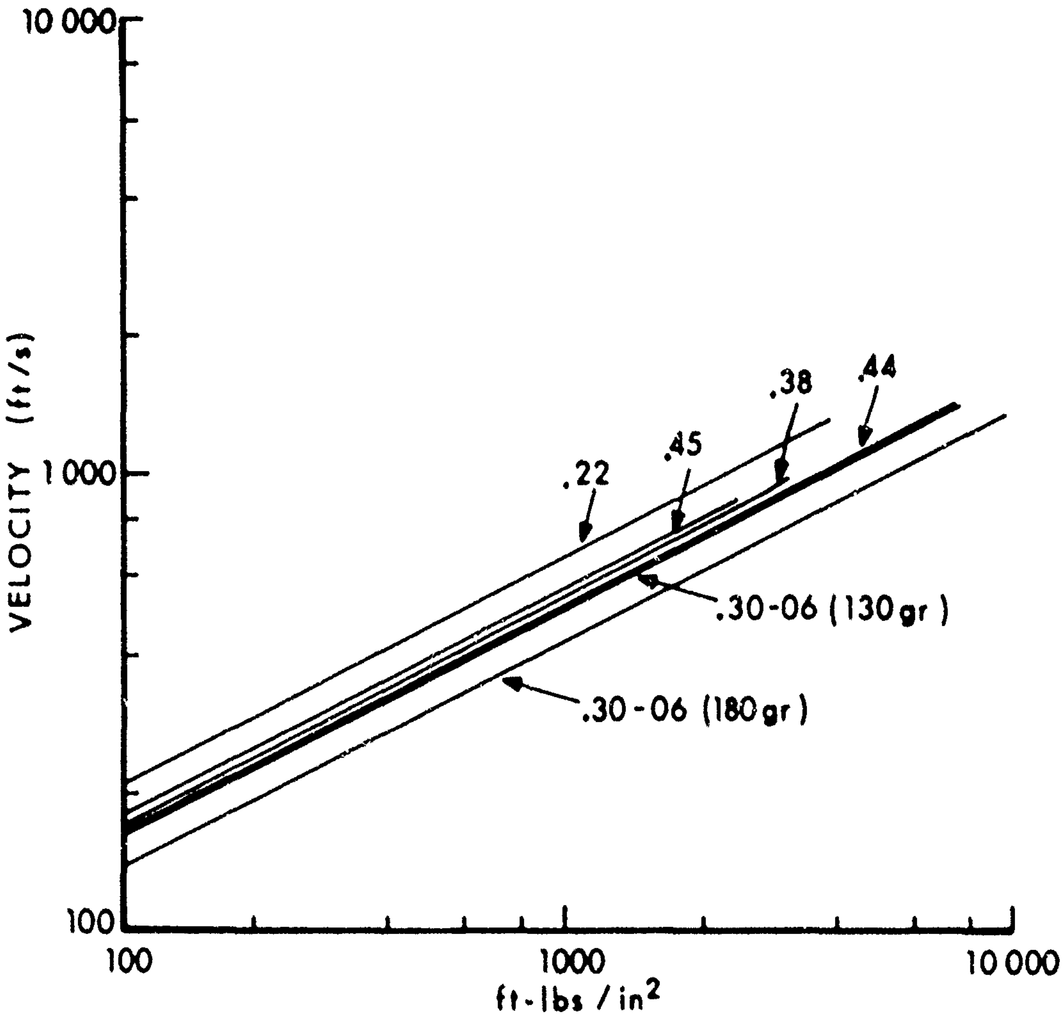


Figure 12. Plot of Impact Energy per Area vs Impact Velocity.

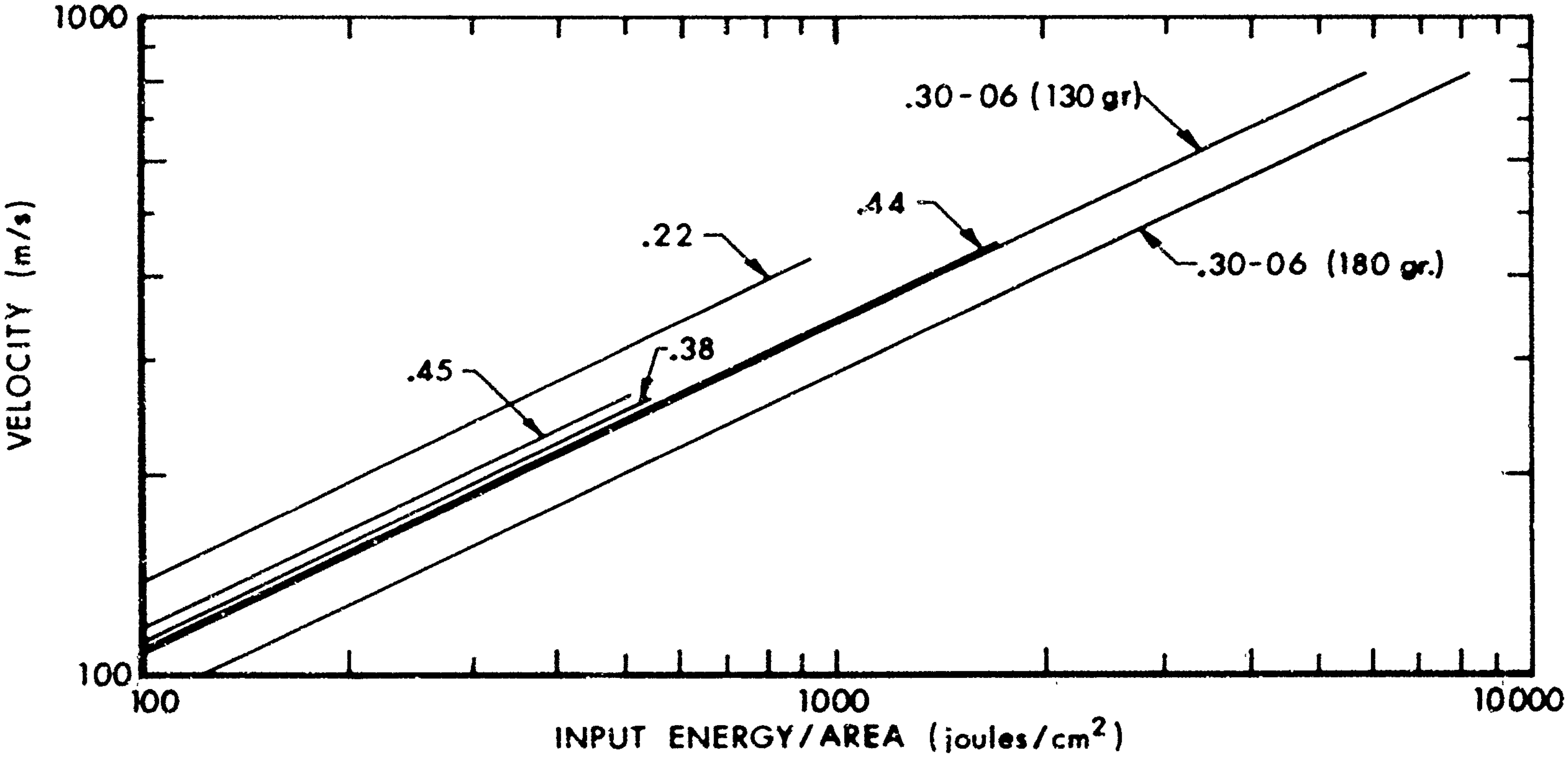


Figure 12a. Plot of Impact Energy per Area vs Impact Velocity.

Table IX. Equivalent Damage Velocities for .30-06; .38-; .44- and .45-Caliber Projectiles

Impact Data from 40-grain, .22-Caliber, High-Velocity, Long Rifle Projectiles				Velocities Required for Same Impact Energy as .22-Caliber Projectiles									
Velocity		Energy		.30-06 130 grain		.38 158 grain		.44 240 grain		.45 230 grain		.30-06 180 grain	
m/s	f/s	joules/cm^2	ft-lbs/in^2	m/s	f/s	m/s	f/s	m/s	f/s	m/s	f/s	m/s	f/s
427	1400	953	4587	331	1086	346*	1138*	338	1109	364*	1194*	280	920
396	1300	819	3945	307	1006	321*	1055*	313	1029	337*	1107*	260	853
366	1200	700	3370	284	931	297*	975*	290	951	312*	1023*	240	788
335	1100	586	2832	259	851	272*	892*	265	870	285*	936*	220	721
305	1000	486	2340	236	775	248	813	241	792	260	852	200	657
290	950	440	2116	225	742	236	777	230	759	247	814	190	630
274	900	392	1887	212	696	222	730	217	712	233	766	180	590
244	800	311	1498	189	620	198	650	193	634	208	682	160	525
213	700	237	1141	165	541	173	567	169	553	181	595	140	459

*Velocities are theoretical since these exceed the maximum muzzle velocities of these weapons. See Table VII.

A graphical presentation of the data given in Table IX is given in Figures 13 and 13a.

Some additional impact tests were conducted using projectiles other than .22-caliber in an attempt to verify this correlation experimentally. Some 130-grain .30-06 projectiles were used, and tests were made against polycarbonate type materials and against glass materials.

Table X presents tabulated data for a comparison of .22-caliber impact tests vs. .30-06-caliber impact tests against polycarbonate type plastic glazing materials. Three tests were made of 40-grain, .22-caliber projectiles against 1.27 cm thick (0.5 in) polycarbonate plastic. Impact velocities were selected arbitrarily to provide different degrees of damage. These were (1) an impact velocity of 361 m/s (1184 f/s), which resulted in complete penetration of the target material, (2) an impact velocity of 317 m/s (1039 f/s), which resulted in a large indentation (large "dimple") in the material but no complete penetration, and (3) an impact velocity of 298 m/s (979 f/s), which resulted in an appreciably smaller indentation in the target material. From the curve in Figure 13 or 13a the following should hold:

a. a 130-grain, .30-06-caliber projectile at an impact velocity of 280 m/s (920 f/s) should be equivalent to a 40-grain, .22-caliber projectile at 361 m/s (1184 f/s), i.e., produce complete penetration through the target;

b. a 130-grain, .30-06-caliber projectile at an impact velocity of 245 m/s (805 f/s) should be equivalent to a 40-grain, .22-caliber projectile at 317 m/s (1039 f/s), i.e., produce a large indentation in the target without a complete penetration;

c. a 130-grain, .30-06-caliber projectile at an impact velocity of 232 m/s (760 f/s) should be equivalent to a 40-grain, .22-caliber projectile at 298 m/s (979 f/s), i.e., produce a small indentation in the target (considerably smaller than an identation at (b) above). The observed results and the data in Table X indicated that this was so. Variations between the expected and actual velocities were considered to be within acceptable limits.

Table XI and Table XII present tabulated data for a comparison of 40-grain, .22-caliber impact tests with 130-grain, .30-06-caliber impact tests against glass-like glazing materials, Materials J and D, respectively. The damage done to glass materials was not as sharply defined as had been the case for the polycarbonate materials. In the tests against glass materials, therefore, comparisons were made on the basis of whether or not any spall was produced from the back surface of the target.

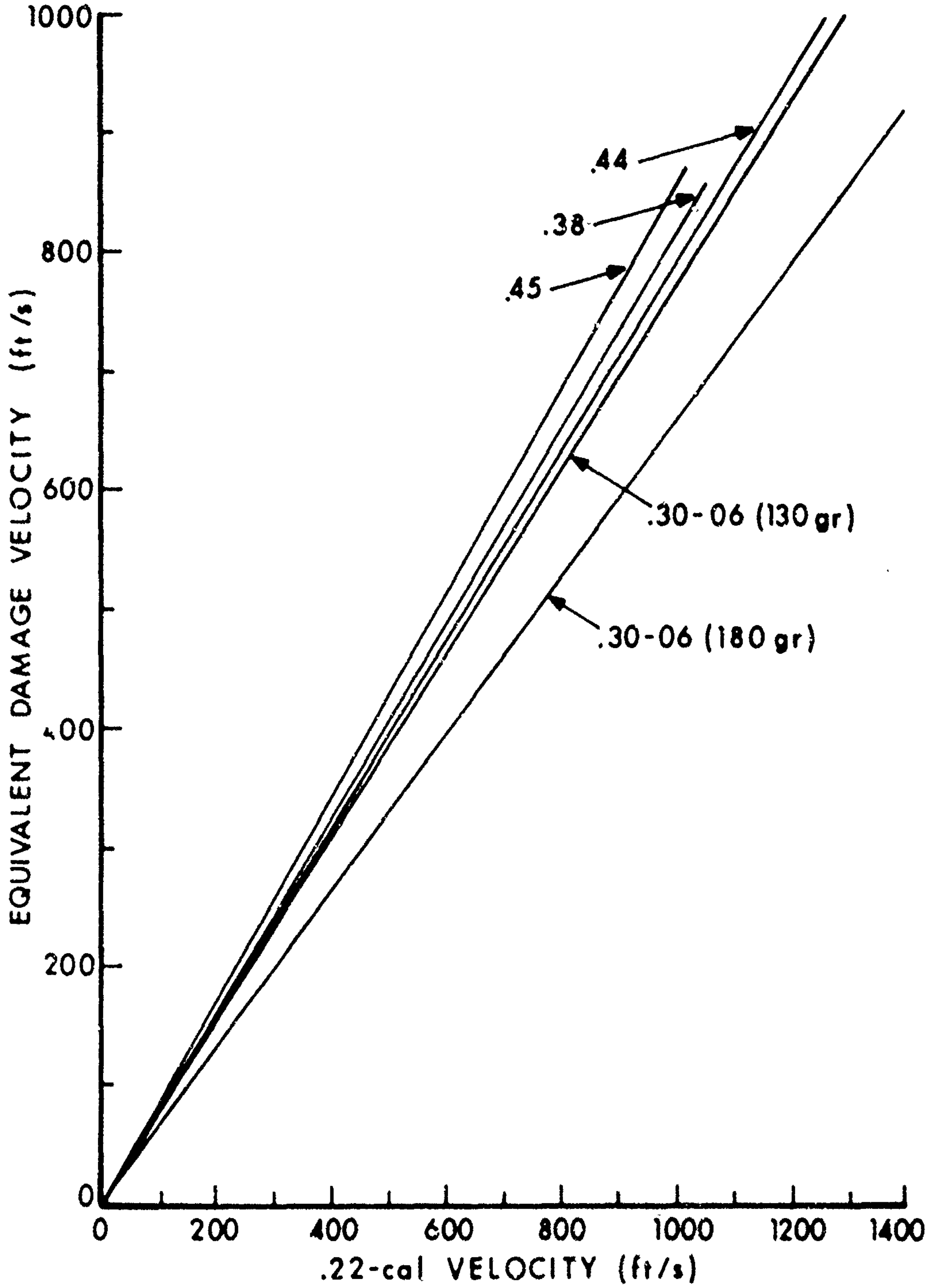


Figure 13. Plot of Equivalent Damage Velocities for .30-06-, .38-, .44-, and .45-Caliber Projectile vs the Impact Velocity of .22-Caliber Projectiles

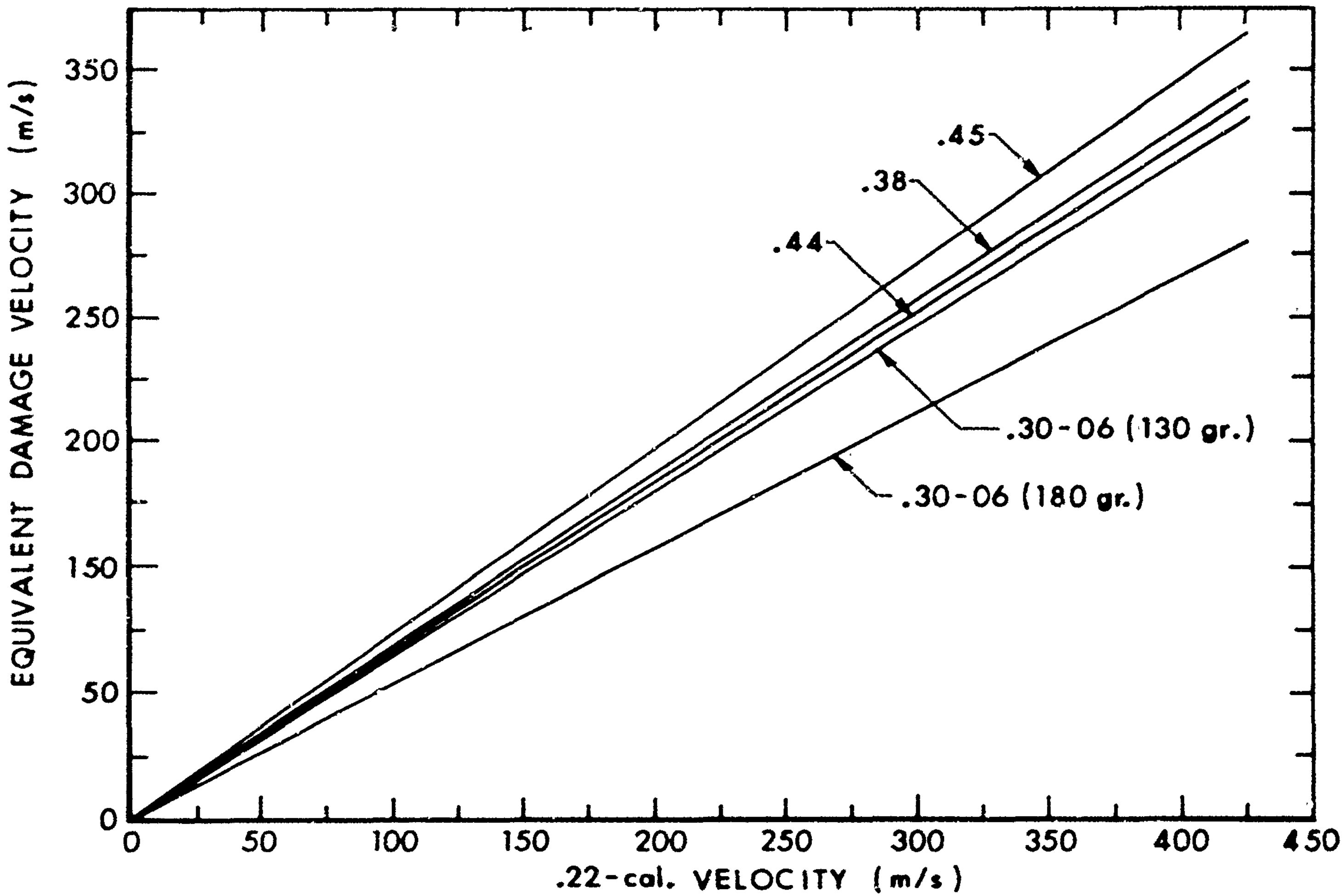


Figure 13a. Plot of Equivalent Damage Velocities for .30-06-, .38-, .44-, and .45-Caliber Projectile vs the Impact Velocity of .22-Caliber Projectiles

Table X. Comparison of .22-Caliber and .30-06-Caliber Projectile Impacts Against Polycarbonate Plastic Glazing Materials

.22 Caliber Impact Data					.30-06-Caliber Impact Data			
velocity			Velocity for equivalent impact energy intensity (from curve, Fig. 13/13a)		Actual velocity of test; actual impact velocity		Percent Variation	
m/s	f/s	Result	m/s	f/s	m/s	f/s	± %	Results
361	1184	Complete penetration	280	920	294	964	+5.0	Complete penetration.
					303	993	+8.2	Complete penetration.
					305	999	+8.9	Complete penetration.
317	1039	Large indentation	245	805	261	885	+6.5	Large indentation; no complete penetration.
317	1039	Large indentation; projectile embedded in target.			264	866	+7.8	Large indentation; no complete penetration.
					244	802	-0.4	Large indentation; no complete penetration.
298	979	Smaller indentation than above	232	761	242	793	+4.3	Small indentation; not as much damage as above.
					210	689	-9.5	Small indentation; not as much damage as above.

Table XI. Comparison of .22-Caliber and .30-06-Caliber Projectile Impacts Against Glazing Material J

.22-Caliber Impact Data			Velocity for equivalent impact energy intensity		.30-06-Caliber Impact Data			
Velocity					Actual measured impact velocity		Percent Variation	
m/s	f/s	Result	m/s	f/s	m/s	f/s	± %	Remarks
359	1179	Large amount of spall.	279	915	275	902	-1.4	Considerable amount of spall produced.
311	1019	Very slight, small amount of spall.	245	805	225	739	-8.2	No spall.
		Almost no spall.			251	823	+2.4	No spall.

Table XII. Comparison of .22-Caliber and .30-06-Caliber Projectile Impacts Against Glazing Material D

.22-Caliber Impact Data			.30-06-Caliber Impact Data					
Velocity m/s	Velocity f/s	Result	Velocity for equivalent impact energy intensity m/s	Velocity for equivalent impact energy intensity f/s	Actual measured impact velocity m/s	Actual measured impact velocity f/s	Percent Variation ± %	Results
378	1241	Considerable amount of spall produced.	293	960	300	985	+2.4	Large amount of spall produced.
311	1021	No spall.	241	790	211	691	-12.4	No spall.
					237	776	-1.7	No spall.
					257	844	+6.6	No spall.

Impact tests of 40-grain, .22-caliber projectiles against Material J resulted in a large amount of cracking and spall at an impact velocity of 359 m/s (1179 f/s), and a very slight amount of spall (almost none) from an impact at 311 m/s (1019 f/s). From Figure 13 or 13a, comparable degrees of damage should be obtained by the impacts of 130-grain, .30-06-caliber projectiles at 279 m/s (915 f/s) and 245 m/s (805 f/s), respectively. Data in Table XI indicated this to be true, within acceptable limits.

Table XII presents similar results of impacts against Material D. Impact tests of 40-grain, .22-caliber projectiles against Material D resulted in a large amount of spall and cracking from an impact velocity of 378 m/s (1241 f/s). No spall was produced from an impact of 311 m/s (1021 f/s). As before, from Figure 13 or 13a, comparable degrees of damage should be produced by impacts of 130-grain, .30-06-caliber projectiles at velocities of 293 m/s (960 f/s) and 241 m/s (790 f/s), respectively. Here again this was the case (within acceptable limits).

The results of the comparison impact tests given in Tables X, XI, and XII seem to indicate that the data in Table IX and Figures 13 and 13a can be used to predict the degree of damage to glazing materials for projectiles other then 40-grain, .22-caliber. It is realized that this is based on a small, limited number of tests on an equally limited number of materials, but a more detailed test program to determine more accurately, or more conclusively, this correlation is beyond the scope, as well as the time frame, of the current program.

F. Projectile Impacts Against Steel (Vehicle Walls)

During the course of the testing program some concern was expressed over whether or not the metal surrounding the windows of railroad vehicles would be able to prevent a projectile from penetrating into the cab of a locomotive (or the interior of a passenger coach or caboose). This could be a threat to personnel also since a vandal may not hit a window when he fires a weapon at a moving train. It would be very impractical to have a glazing material with better impact resistance against a projectile than the metal surrounding it. Table XIII presents a summary of the results from the .22-caliber projectile impacts against various types of steel similar to those used in the construction of railroad vehicles.

As indicated, there were no complete perforations of the metal. It would therefore seem reasonable to assume that these metals in locomotive cabs, passenger coaches, and cabooses would be able to prevent the complete penetration of .22-caliber projectiles fired from any distance up to and including point blank range.

Table XIII. Summary of .22-Caliber Projectile Impacts Against Steel[a]

Type of Material	Thickness		Hardness	Impact Velocity		Results
	cm	in	BHN	m/s	f/s	
EMS 56 Steel	0.4763	0.1875	-	371	1219	No perforation; only a very slight indentation.
Unitized Side Sash Assembly	0.228	0.0897	-	374	1226	Indentation but no complete perforation.
Mild Steel	0.257	0.101	89	347	1138	Projectile embedded in plate; no complete perforation.
4130 Steel	0.183	0.072	130	387	1271	Indentation in plate; no complete perforation.
Mild Steel	0.312	0.123	101	371	1217	Indentation in plate; no complete perforation.

*All tests with target at 0° obliquity; distance from muzzle to target was 4.8 meters (15.75 feet).

IV. CONCLUSIONS

Results of this program have indicated there are several glazing materials currently available that are capable of providing protection for railroad personnel or passengers against the following threats: (1) .22-caliber, high-velocity, long rifle projectiles fired from a maximum distance of approximately 91.4 meters (300 feet); (2) hand-sized objects such as rocks, bottles, half-bricks, etc., thrown from a distance of approximately 8 meters (25 feet); and (3) heavy, suspended objects such as cinder blocks impacted at a vehicle speed of 48 kilometers per hour (30 mph). Materials were only evaluated at this time with respect to their impact resistance to these hazards. Any other properties of these glazing materials, such as abrasion resistance or optical characteristics, would need to be evaluated separately. Also, an analysis of the comparative cost effectiveness of each would need to be performed.

The results from a limited number of tests indicate that the degree of damage from the impacts of other types of projectiles can be correlated to the damage level produced by .22-caliber projectile impacts. This would enable the threshold damage velocities (with corresponding distances) of other types of projectiles to be determined without the need for an extensive time-consuming firing program. Instead, a small number of tests could be made to confirm the predicted threshold velocities.

The steel surrounding locomotive cab compartments was determined to be adequate to prevent .22-caliber projectiles from penetrating into the cab and posing a threat to personnel. Similarly, there should be no threat to personnel or passengers in cabooses or coaches caused by .22-caliber projectiles penetrating through the exterior metal walls of these type railroad vehicles. However, any other materials such as aluminum or its alloys that could be used in any of the modern lightweight equipment would require additional testing.

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APPENDIX A

PERFORMANCE SPECIFICATION FOR RAILROAD GLAZING MATERIALS (PROPOSED/TENTATIVE)

Section I. Objective

The objective of this specification is to set forth intrusion protection requirements for personnel enclosures to apply under the operating conditions of mobile rail vehicles where personnel safety from projectiles is mandated. The performance standards described herein represent minimum protection levels for the total exposed enclosure system including glazing materials, mounting methods and surrounding structural material. The word "target" will be used to describe the individual material component as integrated in the enclosure. While given in terms of simulated tests, the levels stipulated in this specification will reasonably protect the occupants under the actual expected/experienced spectrum of projectiles utilized by vandals.

Section II. General Discussion and Definitions

There is almost an unlimited number of combinations of variations in projectile types, weights, impacting velocities, materials and physical characteristics which are possible. However, a discreet procedure relying upon only two (2) defined tests which are at the practical extremes of projectile mass and velocity are sufficient to ensure adequate protection coverage for the entire set of other possible variation combinations.

Appropriate definitions and considerations are:

A. Ballistics Category: Commonly thought of as "bullet" projectile (P-1) characterized by high velocity and low mass, i.e., velocities in vicinity of sonic range.

B. Heavy Object Category: Commonly thought of as suspended (P-2) or hand thrown projectiles. Characterized by relatively low velocity and high mass, i.e., velocities in vicinity of 1/10 sonic level and mass near 11.34 kilograms (25.0 pounds).

C. Moving Vehicle Exposure Considerations: The tests prescribed simulated actual exposures and have been deliberately set to facilitate objective and repeatable test results. They generally incorporate a set of more severe conditions than "real world". However, the testing structure permits definitive and accurate testing while providing for a confident extrapolation to real life equivalence. Due to the additive directional relative velocities of a moving vehicle, performance specification standard level requirements are modified in accordance with expected/experienced exposure risks. Accordingly, the "heavy object" protection requirements are less for "side" windows, i.e., where potential intrusion is from sources always perpendicular to the direction of predominant relative movement. For purposes of this specification, the pertinent coverage locations are defined as:

Location Category	Description
L-1	Those enclosure locations where the intrusion risk can be from sources where the velocity of the vehicle is additive to that of the major velocity component of the projectile.
L-2	Those locations where the intrusion risk is predominantly from sources which make the resultant relative velocity vector largely independent of the major velocity component of the moving vehicle.

This specification is meant to be operative over the life of the subject personnel enclosures, i.e., such enclosures should be maintained to meet the protection from projectile intrusion levels stipulated.

Section III. Simulated Testing Requirements

A. General Requirements

1. The material to be tested (Target Material) shall be integrated into a "Test Specimen" so that the intrusion protection properties are similar to the intended service application of the personnel enclosure system.

2. Appropriate analysis will be performed to support the similitude of the Target Material in the Test Specimen of Section III.A.1 (above).

3. The test specimen containing the target material will be securely and rigidly attached in a fixture so that the fixtures' own characteristics will not introduce test errors.

4. Target material will be representative of production runs. Randomness of selection will be demonstrated and documented.

5. The Target Material will be full size as produced and installed.

6. The Target Material in the Test Specimen will be positioned at an angle of 0° obliquity (perpendicular to the entry of the defined projectile).

7. The point of impact of the defined projectile will be at the centroid of the Target Material or within a radius of 7.62 cm (3.0 in) of the centroid.

8. Velocity screens or other suitable velocity measuring devices will be positioned so as to measure the impact velocity of the defined projectile within a ± 10% accuracy tolerance; with test modifications made to guarantee that the stipulated minimum velocity requirements are met.

9. A "Witness Plate" shall be mounted parallel to and at a distance of 15.24 cm (6.0 in) in back of the Target Material. The Witness Plate shall have at least an area which will cover the full map of the Target Material.

10. The "Witness Plate" shall be an unbacked sheet of maximum 0.0051 cm (0.002 in) aluminum foil stretched within the perimeter of a suitable frame to provide a taut surface.

11. The projectile velocities, characteristics and other pertinent procedures will be as specified in Sections III.B and III.C.

12. Each Target Material must successfully undergo P-1 and P-2 to be approved.

B. <u>Ballistic Test Specifications (P-1)</u>

1. These tests (P-1) will apply to both L-1 and L-2 locations.

2. Testing will conform to the provisions of Section III, General Requirements.

3. The projectile utilized will be a 40-grain, .22-caliber, high velocity, long rifle type. A minimum impact velocity of 290 meters per second (950 feet per second) will be required.

4. Three consecutive impacts meeting both the requirements of this Section (III.B) and of Section IV are necessary for acceptance under P-1.

C. <u>Heavy Object Test Specifications (P-2)</u>

1. These tests (P-2) will apply to L-1 and L-2 locations as indicated in Table 1.

2. Testing will conform to the provisions of Section III, General Requirements.

3. The projectile utilized will be as prescribed in Table 1 which also contains the impact velocity requirements together with reference specifications and other descriptions.

4. Two consecutive impacts meeting both the requirements of this Section (III.C) and of Section IV are necessary for acceptance under P-2.

Table 1

Item	Object	Refer. No.	Description	Min. Wt.	Req'd Min Relative Velocity at Impact.	Apply to
1	Cinder Block	ASTM C331 and ASTMC90	Nominal dimensions 20.3 cm x 20.3 cm x 40.6 cm (8.0 in x 8.0 in x 16.0 in) with impact point to be on a corner.	10.9 kg (24.0 lb)	13.4 m/s (44.0 f/s)	L-1
2	Cinder Block	Same as 1	Same as 1	same as 1	8.8 m/s (29.0 f/s)	L-2

Section IV. Criteria for Successful Outcomes

Each prescribed individual test and the prescribed set of required tests will not be considered successful unless they meet the requirements of this Section.

A. Projectile Penetration

There shall be no penetration of the back surface (side closest to Witness Plate) of the Target Material by the projectile. Partial penetration of the impact (front) surface of the Target Material does not constitute a failure.

B. Target Material Fragment Penetration

There shall be no penetration of particles from the back side of the Target Material through the back side of the prescribed Witness Plate.

C. Target Material Selection

1. A separate Target Material sample will be used for each test. The selected Target Material samples will be representative of, and be obtained randomly from, normal production practice "runs".

2. If the Target Material (and integration in the Test Specimens) to be subjected to test is not the same (dimensions, surfaces, etc) as the intended real world installation, a test deviation request, with supporting documentation and reasons, must be submitted to the FRA Administrator; who will approve or disapprove such testing for the

purpose of qualification under these specifications.

D. Application and Miscellaneous

1. The successive successful frequency of impacts per Section III.B.5 and II.C.4 stipulations are required.

2. These "Personnel Enclosure Performance Specifications for Protection from Projectile Intrusions" are not intended, in any way, to modify or eliminate other existing specifications concerning other properties such as:

a. Visual
b. Thermal
c. Abrasion
d. Corrosion
e. Audio
f. Chemical
g. Etc.

Section V. Documentation

1. Compliance with the requirements of the Specification shall be verified by testing and analysis as prescribed herein. A complete record of each test verification shall be made, retained and, upon request, made available for inspection and copying by authorized representatives of the Department.

2. Testing records shall contain all pertinent original data logs and documentation that selection of samples, test set-ups, test measuring devices, test procedures, Target Material, Test Specimens, Success Criteria application and other procedures applied were in accordance with provisions of this specification.

3. Documentation shall be made to demonstrate that testing practices conform to recognized acceptable practices and were accomplished by qualified personnel.

APPENDIX B

SUMMARY OF TEST DATA: PROJECTILE IMPACTS AGAINST GLAZING MATERIALS

TEST MATERIAL A

Test No.	Velocity f/s	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
2505A7	719.3	219.2	850	259	62	46	Impact side was cracked but there was no complete penetration; no spall.
2505C7	1052.7	320.9	145	44	133	98	No complete penetration; moderate spall off back plate.
2705A7	1237.0	377.0	16	5	184	136	Muzzle velocity, no complete penetration; large amount of spall; severe cracking.

TEST MATERIAL B

Test No.	Velocity f/s	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
2705D7	771.0	235.0	690	210	72	53	Panel cracked at impact point. No complete penetration; no spall.
2705E7	1069.0	325.8	125	38	137	101	Panel cracked at impact; some glass on front was knocked off. No complete penetration; no spall.
2705F7*	1222.0	372.5	16	5	180	133	At muzzle velocity; severe cracking on impact side. No complete penetration; no spall.

TEST MATERIAL C

Test No.	Velocity f/s	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
2505D7	399.9	121.9	2230	680	19	14	No damage of any kind.
2505E7	864.0	263.4	460	140	90	66	Slight indentation (.0625") and bulge. No complete penetration; no spall.
2505F7	958.5	292.2	280	85	111	82	Indentation of 0.1875"; slight bulge. No complete penetration; no spall.
2505G7	918.7	280.0	350	107	102	75	Indentation of 0.125"; very slight bulge. No complete penetration; no spall.
2505H7*	1039.3	316.8	160	49	130	96	*Std. vel. projectile. No complete penetration. Proj. embedded in plate bulge but no spall.
2505J7	1250.8	381.2	16	5	188	139	Muzzle velocity; complete penetration; neat hole, slight spall.

TEST MATERIAL D

Test No.	Velocity f/s	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
2705G7	1241.0	378.3	16	5	185	137	Muzzle velocity. No complete penetration, but there was severe cracking and much spall.
2010B7	1020.8	311.1	185	56	125	92	Cracked at impact point; no spall.

TEST MATERIAL E

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
2705H7	926.9	282.5	335	102	103	76	Knocked 1.25" diameter hole in plate.
0106A7	588.6	179.4	1330	405	42	31	No apparent damage to target plate.
0106B7	787.5	240.0	640	195	75	55	Small indentation in plate but no complete penetration and no spall.
0106C7	738.7	225.2	790	241	66	48	Small indentation in plate but no complete penetration and no spall.
0106D7	521.6	158.9	1620	494	33	24	No apparent damage to target plate.
0106E7	1064.2	324.4	130	40	136	101	Complete penetration of target plate. "Neat" hole; not much spall.
0106F7	1144.3	348.8	16	5	158	116	Muzzle vel. Complete penetration of target plate; neat hole; little or no spall.
0106G7	1018.8	310.5	190	58	125	92	Complete penetration; no spall. Appeared to barely get through.
0106H7	942.2	287.2	310	95	107	79	Appeared to be on verge of just going through. No complete penetration; no spall.
0106J7	1002.8	305.7	210	64	121	89	Knocked 1.0" plug out of plate.
0106K7	939.7	286.4	315	96	106	78	Same as above.

TEST MATERIAL F

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
0507A7	1122.9	342.3	16	5	152	112	No complete penetration; large amount of spall; plate cracked (muzzle velocity).
0507B7	1174.1	357.9	16	5	166	122	No complete penetration; very large amount of spall; target severely cracked.
1107D7	766.2	233.5	700	213	71	52	No penetration; no spall; slight cracking.
1107E7	1025.2	312.5	180	55	127	93	No penetration; light to moderate amount of spall.
2010D(2)7	1028.4	313.5	175	53	127	94	Considerable spall and cracking.

TEST MATERIAL G

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
0507C7	930.3	283.6	330	101	104	77	No penetration; no spall; target severely cracked.
0507D7	1158.9	353.2	16	5	162	119	No complete penetration; very large amount of spall; very severe cracking.
2010E7	1044.3	318.3	155	47	131	97	Cracking at impact; no spall.

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
					TEST MATERIAL H		
0507J7	1200.3	365.9	16	5	173	128	No complete penetration; large amount of spall; some cracking.
1107G7	998.7	304.4	220	67	120	89	No penetration; slight amount of spall.
					TEST MATERIAL I		
0507H7	1122.6	342.2	16	5	152	112	No complete penetration; no spall; little damage.
0507M7*	1248.0	380.4	16	5	187	138	No penetration; no spall; glass knocked off at impact point.
					TEST MATERIAL J		
0507G7	1178.7	359.3	16	5	167	123	No complete penetration; moderate to severe spall (slivers); moderate cracking.
1107H7	647.3	197.3	1100	335	50	37	No penetration; no spall; very slight damage.
1107J7	1019.2	310.7	185	56	125	92	No complete penetration; very slight amount of spall; slight cracking.
2010A7	1035.6	315.7	165	50	129	95	Cracked on impact side; no spall.

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
					TEST MATERIAL K		
2607A7	1198.6	365.3	16	5	173	127	No complete penetration; large amount of spall. Not much cracking.
2607B7	962.9	293.5	275	84	112	82	About same as above.
2607C7	589.7	179.7	1330	405	42	31	No penetration; no spall; very little damage.
2607D7	665.8	202.9	1030	314	53	39	No complete penetration; slight amount of spall.
					TEST MATERIAL L		
2607E7	1132.8	345.3	16	5	154	114	No complete penetration; no spall; panel became bowed after impact.
2607F7	673.4	205.3	1005	306	55	40	Same as above.
					TEST MATERIAL M		
0507F7	1162.8	354.4	16	5	163	120	No complete penetration; large amount of spall; severe cracking.
1107B7	709.2	216.2	880	268	61	45	No penetration; no spall; very little damage.
1107C7	1045.5	318.7	155	47	132	97	No complete penetration; no spall; target badly cracked.
0707A7	1249.9	381.0	16	5	188	139	No complete penetration; very severe spalling was produced; severe cracking.

TEST MATERIAL N

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
0507E7	1185.6	361.4	16	5	169	125	No complete penetration; large amount of spall; very severe cracking.
1107A7	698.8	213.0	915	279	59	43	No penetration; no spall; plate was severely cracked.
2010C7	1073.8	327.3	120	37	139	102	Severe cracking; considerable spall.

TEST MATERIAL O

Test No.	Velocity f/t	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
0902A8	1112.9	339.2	80	24	149	110	Bulge on back of target; no complete penetration; no spall.
0902B8	*	*	*	*	*	*	Almost complete penetration. Bulge on back of target was split. No spall.
0902C8	1132.1	345.1	60	18	154	114	Large bulge on back of target but no complete penetration. No spall.
**	1220.9	372.1	50	15	179.6	132.5	Bulge on back of target; crack in bulge. No complete penetration. No spall.
BA0228L8	1292.9	394.1	20	6	201.5	148.5	Complete penetration.

*Counters did not function; no velocities or distances obtained.

**Data is average of 4 tests. Results of all 4 were the same.

TEST MATERIAL P

Test	Velocity		Diatnace		Energy		
No.	f/t	m/s	ft	M	Joules	ft-lbs	Results/Remarks
BA0302A8	1023.8	312.1	300	91.4	126	93	Target cracked but no complete penetration.
BA0302B8	-	-	300	91.4	-	-	Same as above. Missed velocity.
BA0302C8	1028.9	313.6	300	91.4	127	94	Target cracked; no complete penetration.
BA0302D8	1040.8	317.2	300	91.4	130	96	Same as above.
BA0302E8	1011.8	308.4	300	91.4	123	91	Same as above.
BA0302F8	1025.0	312.4	300	91.4	126	93	Same as above.
*	1026.1	312.7	300	91.4	127	93	See note below.

*Average of 5 tests.

NOTE: Appeared to be at or near limit - appeared that increase in velocity would result in complete penetration. Decrease in velocity would obviously not penetrate.

TEST MATERIAL Q

Test No.	Velocity f/s	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
1	934	284.7	320	97.5	105	77	Bulge in target; no complete penetration.
2	945	288.0	305	93.0	107	79	Bulge in target; no complete penetration.
3	960	292.6	280	85.3	111	82	Bulge in target; no complete penetration.
4	977	297.8	250	76.2	115	85	Bulge in target; no complete penetration.
5	989	301.4	230	70.1	118	87	Bulge in target; no complete penetration.
6	1006	306.6	205	62.5	122	90	Bulge in target; cracked but no complete penetration; no spall.
7	1008	307.2	200	61.0	122	90	Complete penetration.
8	1016	309.7	190	57.9	124	92	Complete penetration.
9	1053	321.0	145	44.2	134	99	Complete penetration.
10	1069	325.8	125	38.1	138	102	Complete penetration.

TEST MATERIAL T

Test No.	Velocity f/s	Velocity m/s	Distance ft	Distance M	Energy Joules	Energy ft-lbs	Results/Remarks
BA0411D8	1060*	323*	150	46	135	100	Bulge in back of target; slight crack in bulge, but no spall and no penetration.
BA0411E8	1102*	336*	100	31	146	108	Complete penetration through target.

*Average of 5 tests from same distance.

APPENDIX C

SUMMARY OF TEST DATA: CINDER BLOCK IMPACTS AGAINST GLAZING MATERIALS

TEST MATERIAL A

Test No.	KM/HR	Impact Velocity MPH	F/S	M/S	Impact Energy Joules	Ft-Lbs	Results/Remarks
BA 0909F7	64.4	40	58.7	17.9	1923	1418	Cinder block passed completely through glazing material in one piece. Very large amount of spall. Large hole put in test material.
BA 0913A7	32.2	20	29.3	8.9	476	351	Considerable amount of spall; moderate to severe cracking. Small hole in test material.
BA0914A7	16.1	10	14.7	4.5	122	90	Moderate amount of cracking; very, very little spall produced (almost no spall).

TEST MATERIAL B

Test No.	KM/HR	Impact Velocity MPH	F/S	M/S	Impact Energy Joules	Ft-Lbs	Results/Remarks
BA 0912D7	96.5	60	88.0	26.8	4311	3179	Severe cracking and considerable amount of spall. Small hole in material.
BA 0912H7	64.4	40	58.7	17.9	1923	1418	Very, very severe cracking but almost no spall. Only a very, very small amount of spall was noted.
BA 0913B7	48.3	30	44.0	13.4	1078	795	No cracking and no spall. No damage other than some "scuff" marks.

Test No.	Impact Velocity KM/HR	MPH	F/S	M/S	Impact Energy Joules	Ft-Lbs	Results/Remarks
TEST MATERIAL C							
BA 0909B7	96.5	60	88.0	26.8	4311	3179	No damage occured to the test material. "Scuff" marks were the only observed effect.
TEST MATERIAL D							
BA 0908B7	64.4	40	58.7	17.9	1923	1418	No cracking and no spall were observed. No damage.
BA 0908C7	96.5	60	88.0	26.8	4311	3179	Severe cracking and a considerable amount of spall was observed.
BA 0913C7	80.5	50	73.4	22.4	3012	2221	Moderate cracking on impact side but no cracking and no spall on the back surface (inside surface).
TEST MATERIAL E							
BA 0915H7	80.5	50	73.4	22.4	3012	2221	There was an indentation in the test material but there was no cracking and no spall.

Test No.	Impact Velocity KM/HR	MPH	F/S	M/S	Impact Energy Joules	Ft-Lbs	Results/Remarks
				TEST MATERIAL F			
BA 0912F7	64.4	40	58.7	17.9	1923	1418	Severe cracking and a very large amount of spall was produced.
BA 0913D7	32.2	20	29.3	8.9	476	351	Severe cracking and considerable to moderate spall.
BA 0914B7	16.1	10	14.7	4.5	122	90	Moderate cracking on front and back but no spall was observed.
				TEST MATERIAL G			
BA 0912G7	64.4	40	58.7	17.9	1923	1418	Severe cracking, small and dense cracks; no spall.
BA 0914D7	48.3	30	44.0	13.4	1078	795	Severe cracking on front; dense, small cracks onback; no spall.
				TEST MATERIAL H			
BA 0909D7	32.2	20	29.3	8.9	476	351	Severe cracking; "L" shaped hole in material; considerable spall.
BA 0913G7	16.1	10	14.7	4.5	122	90	Moderate cracking; moderate spall.

Test No.	KM/HR	Impact Velocity MPH	F/S	M/S	Impact Energy Joules	Ft-lbs	Results/Remarks
					TEST MATERIAL I		
BA 0912E7	64.4	40	58.7	17.9	1923	1418	Severe cracking; very little spall.
BA 0913H7	48.3	30	44.0	13.4	1078	795	Severe cracking; slight spall.
BA 0914C7	32.2	20	29.3	8.9	476	351	Moderate cracking on front; slight cracking, no spall on back.
					TEST MATERIAL J		
BA 0909A7	64.4	40	58.7	17.9	1923	1418	Severe cracking; much spall; no complete penetration.
BA 0909E7	32.2	20	29.3	8.9	476	351	Severe cracking and considerable spall. Complete penetration of test material (inverted "T").
BA 0913I7	16.1	10	14.7	4.5	122	90	Moderate cracking; no spall.
					TEST MATERIAL K		
BA 0912C7	96.5	60	88.0	26.8	4311	3179	Severe cracking; very little spall.
BA 0913J7	80.5	50	73.4	22.4	3012	2221	Severe cracking on front; dense, small cracks on back, but no spall.
					TEST MATERIAL L		
BA 0912B7	96.5	60	88.0	26.8	4311	3179	Very severe cracking on front; "dimple" in back but no spall.

Test No.	KM/HR	Impact Velocity MPH	F/S	M/S	Impact Energy Joules	Ft-lbs	Results/Remarks
					TEST MATERIAL M		
BA 0909C7	64.4	40	58.7	17.9	1923	1418	Severe cracking; severe spall.
BA 0913E7	32.2	20	29.3	8.9	476	351	Severe cracking on front; small, dense cracks on back, but no spall.
BA 0914E7	48.3	30	44.0	13.4	1078	795	Severe cracking on front; many very fine, small cracks on back, but no spall.
					TEST MATERIAL N		
BA 0913F7	64.4	40	58.7	17.9	1923	1418	Front severely cracked; dense, small cracks on back with small amount of spall.
BA 0914F7	48.3	30	44.0	13.4	1078	795	Front moderately cracked; no spall from back.
					TEST MATERIAL O		
BA 0303A8	80.5	50	73.4	22.4	3012	2221	No damage to material except for some "scuff" marks.
					TEST MATERIAL Q		
BA 0411C8	64.4	40	58.7	17.9	1923	1418	Slight indentation in target from corner of block, no spall; no penetration.

TEST MATERIAL R

Test No.	Impact Velocity KM/HR	MPH	F/S	M/S	Impact Energy Joules	Ft-lbs	Results/Remarks
BA 0307F8	64.4	40	58.7	17.9	1923	1418	Impact side of target was badly cracked. Back side indicated little or no spall produced (if any, just a fine powder).
BA 0307G8	80.5	50	73.4	22.4	3012	2221	Damage appeared to be about same as at 64.4 Km/hr (40 mph). Appeared to be little or no spall produced.
BA 0307H8	96.5	60	88.0	26.8	4311	3179	Damage did not appear to be any worse than that for 80.5 or 64.4 Km/hr (50 or 40 mph). No appreciable increase in amount of spall produce (little or no spall).

TEST MATERIAL S

Test No.	Impact Velocity KM/HR	MPH	F/S	M/S	Impact Energy Joules	Ft-lbs	Results/Remarks
BA 0307I8	96.5	60	88.0	26.8	4311	3179	Severe cracking and considerable spall.
BA 0308A8	64.4	40	58.7	17.9	1923	1418	Severe cracking and spalling.
BA 0308B8	48.3	30	44.0	13.4	1078	795	Less spall than above but still produced; moderate spall.

APPENDIX D

SUMMARY OF TEST DATA: RAILROAD SPIKE IMPACTS AGAINST GLAZING MATERIALS

Test Conditions*: Impact Object: Railroad Spike.

Weight: 0.26 Kg (9 oz/0.56 lb).

Impact Velocity: 80.5 Km/hr (50 mph); 22.4 m/s (73.4 f/s).

Impact Energy: 65.2 joules (47 ft-lbs).

Test Material	Results and/or Remarks
A	Moderate amount of cracking; moderate amount of spall.
D	No damage.
E	Very slight indentation; no spall; no damage.
F	Small hole completely through plate; heavy concentrated spall (moderate).
H	Spike embedded in plate; severe spall.
I	No spall.
J	Severe spall.
M	No spall.
N	No spall.

APPENDIX E

SUMMARY OF TEST DATA: PROJECTILE IMPACTS AGAINST STEEL (VEHICLE WALL MATERIALS)

Projectile Impacts Against Steel (Cab Wall Materials)*

Material	Thickness cm	Thickness in	Hardness BHN	Impact Velocity m/s	Impact Velocity f/s	Results/Remarks
EMS 56 Steel	0.4763	0.1875	-	371	1219	Slight indentation; no perforation.
Unitized Side Sash Assembly**	0.227	0.0897	-	374	1226	Indentation; no perforation.
Mild Steel	0.257	0.101	89	347	1138	Projectile embedded in plate but no perforation.
4130 Steel	0.183	0.072	130	387	1271	Indentation; no perforation.
Mild Steel	0.312	0.123	101	371	1217	Indentation; no perforation.

*Conditions for all tests: 0° obliquity, @ muzzle velocity (15.75 feet, gun to target).

**Hot rolled sheet steel.

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